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SURVIVAL AT SEA: THE EFFECTS OF PROTECTIVE CLOTHING AND SURVIVOR LOCATION ON CORE AND SKIN TEMPERATURES

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NOVEMBER 1986

FINAL REPORT

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16. Abstract

Different types of protective clothing for maritime personnel were compared in 3, simulated, survival environments: immersion in cold, rough seas; exposure to cold wind, spray and waves atop an overturned boat; and exposure to cold air and waves in an open, one-man liferaft. The test garments were: flight suit (FS); two-piece wet suit (WS); insulated, loose-fitting aviation (AC) and boatcrew (BC) coveralls; uninsulated dry suit (NI); NI with a 5 cm tear in the shoulder seam (NX). All garments were worn over cotton thermal underwear; an additional layer of insulated, short-sleeve underwear was worn with NI and NX. 8 Coast Guard crewmen were the test subjects; mean age = 23 yrs; mean ht. = 175 cm; mean wt. = 72 kg; mean body fat = 11%. Mean water temp. was 6.1°C. Mean air temp. was 7.7°C. Wind and spray were artificially created at 7.5-10 m/sec. Seas were 1.5 m swells and 1.5 m breaking waves every 30-45 sec. Mean change in mean weighted skin temps (Δ°C) and mean rectal temp. cooling rates (°C/hr), respectively, were as follows for immersion in rough seas: FS = -21, 5.83; NX = -17.4, 3.28; BC = -18.8, 2.87; AC = -15.0, 2.81; WS = -12.7, 1.71; NI = -7.7, 0.86. For exposure to wind, spray and waves on the overturned boat these variables were: FS = -12.8, 2.52; BC = -7.5, 0.95; AC = -5.6, 0.70; WS = -7.8, 0.64. For exposure to cold air and waves in the raft these variables were: FS = -15.5, 3.42; NX = -7.0, 1.14; AC = -8.4, 0.82; WS = -6.6, 0.64; NI = -3.6, 0.62. Significant differences between cooling rates in water and those on the boat or in the raft were found for all garments except NI and WS (boat). The results demonstrate that survivors maintain higher skin temps. and slower cooling rates out of the water, even when exposed to continuous wind, spray and waves than when they remain immersed in rough seas. Insulated, intact dry-suits provide better immersion protection than do either tight-fitting wet suits or loose-fitting coveralls; leaky "dry" suits provide no better protection than do loose-fitting coveralls. The best survival environment is provided by the one-man liferaft. Linear cooling rates were used to estimate survival times in 6.1°C rough seas for personnel wearing each of the test garment-ensembles.

17. Key Words

Hypothermia, Immersion, Exposure, Wind-chill, Protective clothing, Liferaft, Sea survival

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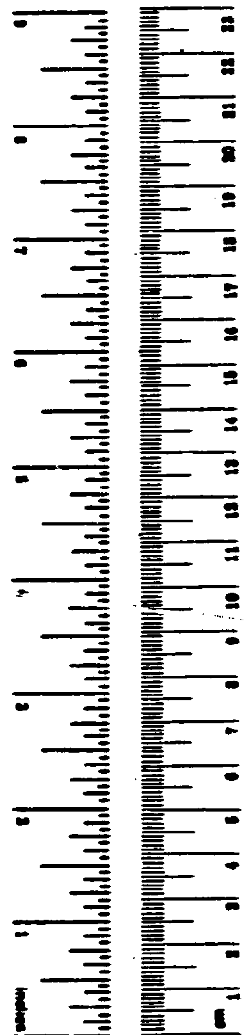
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

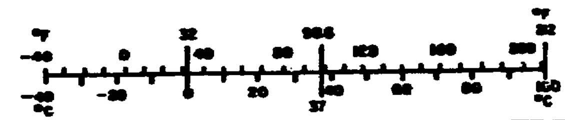
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

Survivors of maritime mishaps in cold, rough seas confront two, acute, life-threatening problems: drowning and hypothermia (1-5). To maintain airway freeboard, a survivor must have adequate buoyancy to keep his head afloat and must possess both the physical skills and psychological aptitude to combat the effects of wave action (1,6). Although a personal flotation device (PFD) assists in maintenance of airway freeboard, waves can still submerge a survivor's head, even in moderate sea-states (7-10). A survivor can reduce his risk of drowning in rough seas by either climbing atop a capsized vessel or aircraft or by entering a liferaft (1,6,9). In both these environments, however, the survivor may still have to cope with the effects of cold wind, spray and waves.

To prevent immersion hypothermia, a survivor must wear adequate protective clothing to minimize conductive heat loss to the water. Insulated garments for this purpose have either "wet" or "dry" characteristics. "Wet" garments (e.g. wet-suits, insulated coveralls, etc.) permit direct contact between the water and the survivor's body; "dry" garments (e.g. immersion suits, coveralls with water-tight neck and wrist seals, etc.) exclude water from contact with the survivor's body.

Studies on the degree of protection provided by such clothing have usually been conducted in a laboratory or other calm-water setting (11-20). Many maritime mishaps, however, occur in rough seas (21-25) where a survivor's cooling rate may be affected by swimming to maintain airway freeboard (26), passive movements of the body by waves (27), flushing of cold water through "wet" suits (28) and leaking of cold water into

"dry" suits (20,29). Two recent studies demonstrated significantly faster cooling rates for human volunteers wearing "wet" protective garments in rough water (30) or moving water (28) than in calm water. Another recent study showed higher energy expenditure and faster cooling rates for subjects in a wave-tank than for subjects in calm water (31).

The U.S. Coast Guard and other rescue organizations currently recommend that a survivor of a maritime mishap in cold seas get as much of his body out of the water as possible in order to minimize cooling rate and maximize survival time (6,9,32). This recommendation derives from the higher thermal conductivity of water compared to air at the same temperature (33). Scientific studies to verify this recommendation have not yet been performed. Survivors exposed to cold air are still at risk from hypothermia secondary to convective, evaporative and radiation heat losses (33-36). In a rough-sea environment, wind increases the magnitude of convective heat loss (34,37), and spray and periodic wetting from breaking waves cause conductive heat loss as well.

Various studies have measured the insulation in air of different types of cold-weather protective clothing (e.g. down-jackets, woolen shirts, fiber-filled coveralls, etc.) (33,38-40), and clothing that remains dry provides significantly better protection than does clothing that is wet (41-42). No study, however, has evaluated the combined effects on wet clothing of cold wind, spray and periodic immersions in cold water, which might occur for survivors atop a capsized vessel or ditched aircraft in foul weather.

The purpose of this study was to evaluate core temperature cooling rates and skin temperature changes of human volunteers wearing various types of protective clothing in three, realistic, sea-survival environments: 1) immersion in rough seas; 2) exposure to cold wind, spray and waves atop a capsized boat or helicopter; and 3) exposure to cold air and rough seas in a one-man liferaft. The protective clothing included garments currently used by merchant seamen, recreational boaters, fishermen, U. S. Coast Guard aviation and vessel crewmen, and U. S. Navy aircrews. A prototype U. S. Navy aviation "dry" suit and a prototype Navy one-man liferaft were also included.

The hypotheses were: 1) for all test garments, cooling rates are faster and skin temperatures are lower for subjects immersed in rough seas than for subjects atop the boat or in the liferaft; 2) for subjects immersed in rough seas, "dry" insulative garments provide better protection than do "wet" insulative garments, and tight-fitting "wet" garments provide better protection than do loose-fitting "wet" garments; 3) for subjects immersed in rough seas, a leaky "dry" garment provides less protection than does an intact "dry" garment; 4) for subjects in the liferaft or atop the capsized boat, loose-fitting, insulated "wet" protective garments provide better protection than does a tight-fitting wet-suit.

METHODS

A. Experimental Design

The experimental design was a cross-over study using eight subjects, six garment-ensembles and three survival environments. Fifteen

combinations of garment-ensemble and environment were evaluated, and each of the eight subjects participated in each combination. Subjects wore the different garment-ensembles in random order both within and between environmental conditions. Six subjects participated in the tests each day, but no subject participated in more than one test per day in order to ensure physiological homeostasis between experimental trials.

The dependent variables in this study were: 1) rectal temperature; 2) skin temperatures (a weighted-mean of chest, arm, thigh and calf; and forehead); and 3) subjective evaluation of garment-ensemble performance. The independent variables were: 1) garment-ensemble and 2) survival environment.

B. Subjects

The use of human subjects was approved by the University of Washington Human Subjects Review Committee and by the U.S. Coast Guard Chief of Operational Medicine (COMDT (G-KOM)), by the Chief of Safety Programs (COMDT (G-CSP)) and by the Chief of Search and Rescue (COMDT (G-OSR)). The use of humans subjects in this study also conformed to the Recommendations from the Declaration of Helsinki (43).

The subjects were eight, active-duty, male, Coast Guard volunteers, each with experience as a helicopter or lifeboat crewman. They were selected on the basis of anthropometric similarity, swimming skills, physical fitness, experience in search and rescue operations, and the ability to withstand extreme discomfort. Prior to selection, each

subject read and signed an informed consent document. The eight volunteers were not representative of the Coast Guard male population: because of the risks involved in this study, subjects were required to demonstrate better than average physical fitness, swimming ability and competence in rough-sea conditions. In addition, the volunteers had a lower percent body-fat than the average Coast Guard male. Each subject passed a complete physical examination and maximum treadmill stress test prior to the start of the study.

The physical characteristics of the subjects are shown in Table 1. Skinfold thickness was measured with Lange calipers. Percent body-fat was calculated using the mean result of five equations based on skinfold thickness (44-48) and the result of hydrostatic weighing using estimated residual lung volumes (49). Maximum oxygen consumption was calculated from heart rate response to a maximum treadmill exercise test (50).

TABLE 1. PHYSICAL CHARACTERISTICS OF THE SUBJECTS

Subject	Age (yrs)	Weight (kg)	Height (cm)	Skinfold Thickness* (mm)	Body Fat (%)	$\dot{V}O_{2(max)}$ (ml/kg/min)
1	21	70.9	172.1	7.4	7.7	51.8
2	28	67.4	177.8	7.3	7.7	49.1
3	22	70.5	175.3	10.4	10.8	49.2
4	22	66.1	171.5	12.4	14.5	51.1
5	20	74.5	175.3	8.3	9.6	49.3
6	24	76.8	175.3	11.6	12.8	58.2
7	25	74.4	175.3	10.1	11.9	52.1
8	26	72.7	177.2	11.7	13.8	36.9
Means	23.5	71.7	175.0	9.9	11.1	49.7
SEM	1.0	1.3	0.8	0.7	0.9	2.1

*Mean of three sites: triceps, subscapular, and abdominal

C. Garment-Ensembles

The six garment-ensembles in this study represent a sample of cold-weather clothing worn by Coast Guard aircrewmen and vessel crewmen, by Navy aircrewmen, and by recreational boaters, fishermen and commercial maritime personnel. The garment-ensembles are grouped as follows: 1) one control; 2) three "wet" ensembles (one tight-fitting and two loose-fitting ensembles); and 3) two "dry" ensembles (one intact and one with a deliberate leak). The items of clothing comprising each ensemble represent the most frequently used operational configuration. The six garment-ensembles are listed in Table 2 and are briefly described below:

1) Flight Suit (FS): This is the standard, aviation, summerweight coverall worn by military flight crews. It is a single-piece coverall made of Aramid III (Nomex), fire-retardant material. Its Military Supply Catalog designation is CWU-27/P, "Coveralls, Flyers, Summer, Fire-Retardant; MILC-83141A." It has minimal insulation and served as a control garment in these tests. It was worn with the following additional items: flight helmet (SPH-3); leather flight boots and two pair of wool socks; Aramid III briefs and full-length, cotton thermal underwear; 3.2 mm Neoprene closed-cell foam (wet-suit) gloves; and an inflatable personal flotation device (PFD), model LPU-26/P. Figure 1 shows this ensemble.

2) Wet Suit (WS): This "wet" garment is used by military aircrews, by vessel crewmen, and by many civilians as well. It consists of an upper and a lower piece of 4.8 mm Neoprene closed-cell foam. The upper piece fits snugly over the trunk and arms, and it has a beaver-tail for

ensuring tight fit around the groin. The lower piece fits snugly over the lower extremities. The model designation of the wet suit is "2080-4A" from Henderson Aquatics, Milville, NJ. It was worn with the following additional items: a 4.8 mm Neoprene closed-cell foam hood worn underneath the flight helmet; Aramid III briefs and full-length, cotton, thermal underwear; flight boots with two pair of wool socks; wet-suit gloves; and an inflatable PFD (LPU-26/P). Figure 2 shows the wet suit without its accompanying ensemble of life-jacket, helmet, etc.

3) Aviation Coverall (AC): This "wet" garment-ensemble is worn by Coast Guard helicopter personnel flying over cold water (i.e. < 15°C). It is a loose-fitting coverall with an inner and outer lining of Aramid III, fire-retardant material. Its insulation consists of 3.2 mm polyvinyl chloride (PVC) foam throughout. Its model designation is "MAC-10" from Mustang Industries, Vancouver, British Columbia. It was worn with the following additional items: a 3.2 mm Neoprene, closed-cell foam hood worn underneath the flight helmet; Aramid III briefs and full-length, cotton thermal underwear; flight boots with two pair of wool socks; wet-suit gloves; and an inflatable PFD (LPU-26/P). Figure 3 shows the aviation coverall ensemble.

4) Boatcrew Coverall (BC): This "wet" garment is widely used by Coast Guard lifeboat and cutter personnel. It is also used by many civilian recreational boaters, fishermen and commercial maritime personnel. It is a loose-fitting coverall with various widths of PVC foam, as follows: anterior chest, 15.9 mm; back, 7.9 mm; anterior abdomen, 7.9 mm; sleeves, 4.8 mm; upper legs, 4.8 mm. It has a Nylon,

waterproof outer shell and an attached hood insulated with 6.4 mm PVC closed-cell foam. Its model designation is "IFS 580" from Stearns Manufacturing, St. Cloud, MN. It was worn with the following additional items: Aramid III briefs and full-length, cotton thermal underwear; Coast Guard "working blue," cotton uniform shirt and trousers; wool watch cap; flight boots with two pair of wool socks; and wet-suit gloves. Figure 4 shows the boatcrew coverall ensemble.

5) Navy Dry Suit (intact) (NI): This experimental "dry" garment-ensemble is proposed for use by U.S. Navy aircrews flying over cold water in either high-performance, fixed-wing aircraft or in helicopters. It consists of a loose-fitting, polytetraflouroethylene (PTFE), Aramid III coverall with integral booties and watertight wrist and neck seals made of soft, pliable rubber. It has a watertight zipper extending horizontally across the chest at the shoulders from mid-right arm to mid-left arm. The watertight PTFE layer is intended to minimize heat-stress by permitting evaporation of sweat. Its designation is CWU-62/P. It was worn underneath the flight suit (CWU-27/P). It was also worn with the following additional items: Aramid III briefs and full-length, cotton thermal underwear; olefin fiber-filled insulated underwear covering the trunk, mid-arms and mid-thighs; flight boots with two pair of wool socks; flight helmet; parachute torso-harness (MA-2); anti-G suit; and a Navy inflatable life-jacket (LPU-23/P with survival vest (SV-2). The cotton thermal underwear and the olefin fiber-filled insulated underwear are shown in Figure 5, the dry suit itself is shown in Figure 6, and the full dry suit ensemble is shown in Figure 7.

6) Navy Dry Suit (torn) (NX): This ensemble is identical to that

just described, with the exception of a 5.1 cm tear in the left, rear shoulder-seams of the CWU-62/P itself, of all its undergarments, and of the flight suit worn over the CWU-62/P. The tears simulate damage to the garment-ensemble which would likely occur with through-the-canopy ejection from certain types of high-performance aircraft. Figure 8 shows a rear view of the dry suit with the torn left-shoulder seam, and Figure 9 shows a closeup of the tear.

Wet suit gloves were used by all subjects in this study because the type of handwear normally accompanying some of the garment-ensembles (e.g. flight gloves for FS, leather gloves for BC and anti-exposure mittens for NI and NX) could not provide adequate protection (i.e. finger temperatures > 8°C) in the cold water used in this experiment.

All garments were custom-fitted to each subject using normally available sizes and normal fitting procedures. During each test, all garments were configured for maximum protection: zippers were closed; hoods were securely fastened; ankle, wrist and thigh straps were tightened; beaver-tails were deployed; flotation devices were properly worn, etc.

The garment-ensembles were tested in the various survival environments as follows: FS, AC, BC, WS, NI and NX in rough seas; FS, AC, BC, and WS in wind, spray and waves atop the overturned boat; FS, AC, WS, NI and NX in cold air and waves in the one-man liferaft. BC was not tested in the raft because vessel crewmen do not normally use an aviation liferaft. NI and NX were not tested atop the overturned boat because most Navy aircraft do not remain afloat after ditching.

Figure 1. Flight Suit Ensemble

Figure 2. Wet Suit

Figure 3. Aviation Coverall Ensemble

Figure 4. Boatcrew Coverall Ensemble

Figure 5. Undergarments for Navy Dry Suit Ensembles

Figure 6. Navy Dry Suit (intact)

Figure 7. Navy Dry Suit Ensemble

Figure 8. Rear view of Navy dry suit showing tear in left shoulder seam

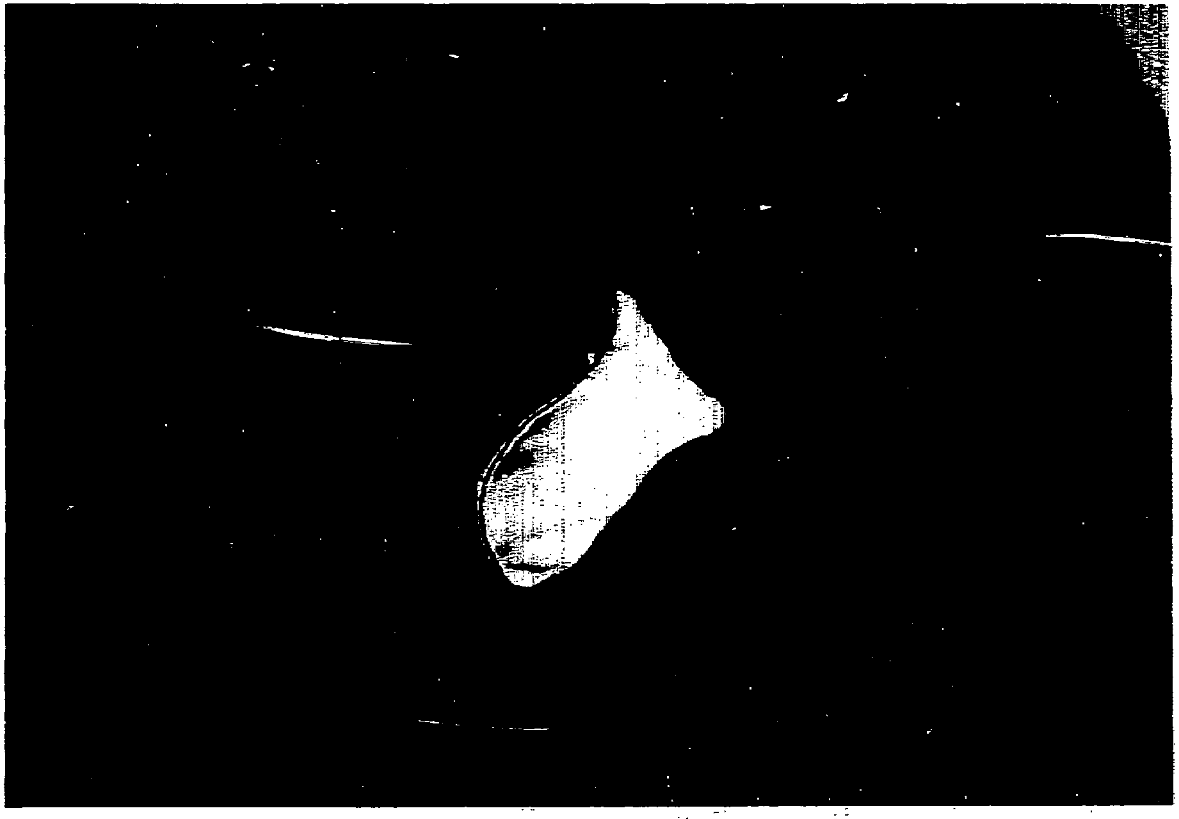

Figure 9. Enlarged view of left shoulder seam in torn Navy dry suit

TABLE 2. GARMENT-ENSEMBLES

Test Garment*	Underwear	Head Covering	Hand Covering	Foot Covering	Additional Equipment
FS	Aramid III briefs; full-length, cotton thermal underwear	Flight helmet (a)	Wet-suit gloves (b)	Wool socks and Flight boots	Inflatable PFD (c)
WS	Same as for FS	Wet-suit hood (d); Flight helmet	Wet-suit gloves	Wool socks and Flight boots	Inflatable PFD
AC	Same as for FS	Wet-suit hood; Flight helmet	Wet-suit gloves	Wool socks and Flight boots	Inflatable PFD
BC	Same as for FS; cotton uniform shirt and trousers	Wool cap under an insulated hood (e)	Wet-suit gloves	Wool socks and Flight boots	None
NI	Same as for FS; olefin fiber-filled, insulated underwear (f)	Flight helmet	Wet-suit gloves	Wool socks and Flight boots	Inflatable PFD; parachute harness(g); anti-G suit
NX	Same as for NI	Flight helmet	Wet-suit gloves	Wool socks and Flight boots	Same as for NI

* FS=flight suit; WS=wet suit; AC=aircrew coverall; BC=boat-crew coverall; NI=Navy dry suit (intact); NX=Navy dry suit (torn). See text for complete description of garments.

(a) Military designation: SPH-3
(b) 3.2 mm Neoprene, closed-cell foam
(c) Coast Guard designation: LPU-26/P
(d) 3.2 mm Neoprene, closed-cell foam
(e) 6.4 mm Neoprene, closed-cell foam with a Nylon cover
(f) Navy designation: CWU-27/P; covers trunk, upper arms and upper legs
(g) Navy designation: MA-2

D. Equipment

A capsized, 17-foot, Coast Guard training boat was used as the test platform both for subjects in the water exposed to rough seas and for subjects atop the boat exposed to wind, spray and breaking waves. The interior of this vessel was fitted with empty barrels to permit a variable amount of bouyancy when the boat was inverted. The outer surface of the hull and the port and starboard sides of the hull were fitted with stainless steel handrails. These permitted subjects in the water to hang onto the capsized boat in the rough seas. The handrails also prevented the subjects atop the capsized boat from being washed overboard by the breaking waves. Strips of non-skid, rubberized decking were applied to the hull for safety in walking and standing on the overturned boat. Finally, the bow of the capsized hull was fitted with stainless steel scaffolding to permit attachment of the wind- and spray-apparatus. Figure 10 shows the test-platform.

The capsized boat was secured in place with mooring lines. One 10 m length of line attached the stern of the boat to a 1400 kg anchor-buoy. Another 10 m length of line attached the bow of the boat to the stern of the 52-foot Motor Lifeboat (MLB) TRIUMPH (which served as a floating laboratory for these studies).

Wind was created artificially with three, Navy, standard, portable blowers (FSN 4140-00-267-0967) working in parallel. (These fans are normally used in fire-figh ing to evacuate smoke from enclosed compartments). A wooden enclosure was constructed to house the three blowers so that their combined output could be channeled through a single duct. The blowers were located on the stern of TRIUMPH and were

powered with its A/C current. The output from the blowers was directed into a 15 m length of flexible, 30 cm diameter ventilation ducting. The proximal end of the ducting was attached to the wooden housing of the blowers; the distal end of the ducting was attached to the scaffolding on the bow of the capsized boat. During experimental trials, wind speed was checked every 30 min with a calibrated, hand-held anemometer. Figure 11 shows the blowers and ducting on the stern of TRIUMPH and, in the background, a subject seated on the test platform in front of the ducting's distal end.

Continuous cold-water spray was directed at the subjects atop the capsized boat through a sprinkler head attached to an ordinary garden hose. This was affixed to the scaffolding on the bow, directly above the opening of the ventilation ducting. The water from the sprinkler was thus directed at the subjects by the wind from the ducting. Ambient water was supplied to the garden hose from a water-pump aboard TRIUMPH. Figure 12 shows the configuration of the wind and spray apparatus on the capsized boat. One subject is shown in the water hanging onto the submerged starboard handrail; two subjects are shown seated in front of the ventilation ducting and sprinkler head. The handrails on the top of the hull are clearly visible; those on the side of the hull are underwater and are not visible.

The one-man liferafts used in this study were prototypes developed by the U.S. Naval Air Development Center, Warminster, PA. The designation of the liferaft is "LRU-18/U, V-Bottom Life-raft." The raft is designed to be packed in a small, soft container and worn as a backpack. It is intended for use by helicopter crews following egress

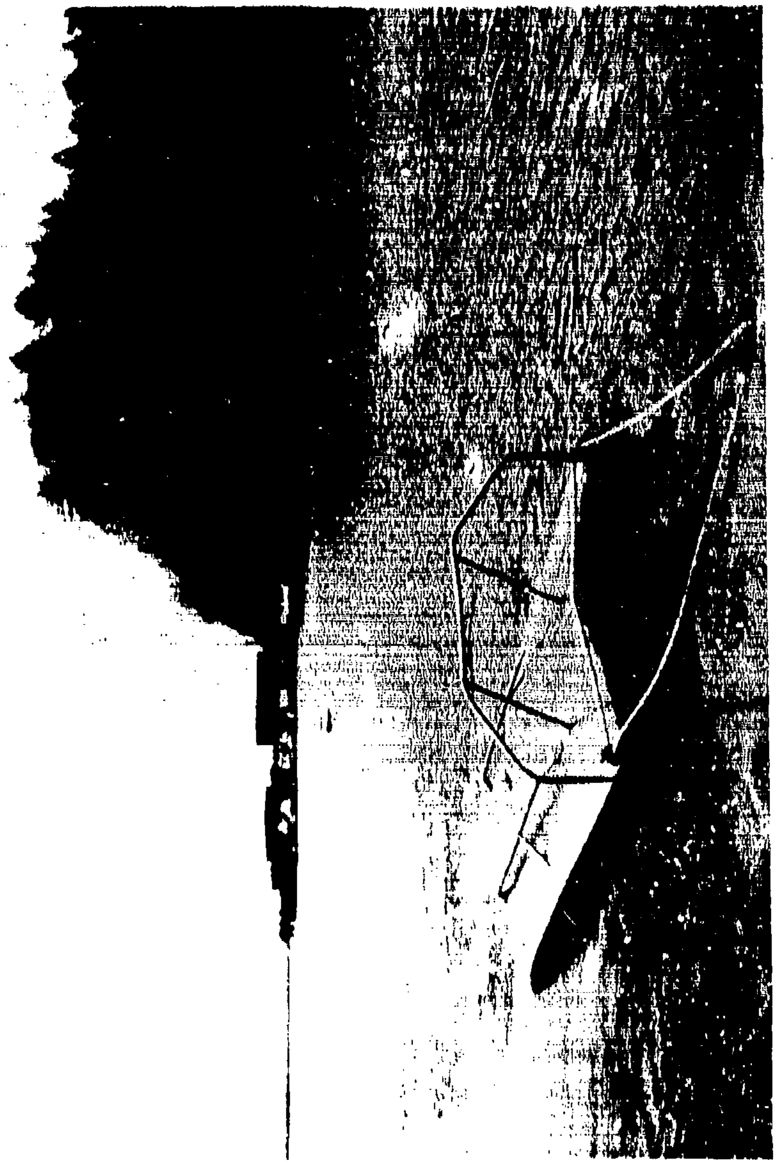

Figure 10. Capsized-boat test-platform with attached scaffolding and hand-rails

Figure 11. Wind-generating blowers and ventilation ducting. Subject seated on test-platform experiences wind speed of 7.5 - 10.0 m/sec (15-18 knots).

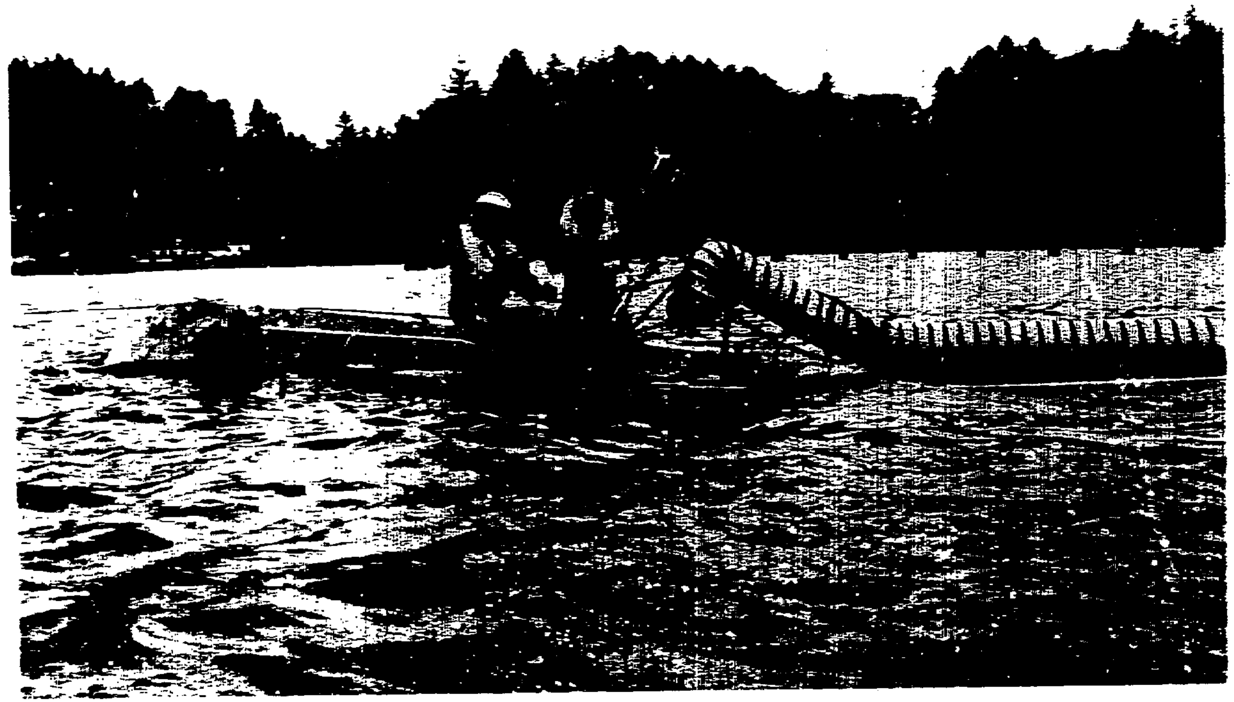

Figure 12. Capsized-boat test-platform showing two subjects exposed to continuous wind and spray atop the boat and one subject in the water, prior to the initiation of rough seas.

from a ditched or capsized aircraft, when the multi-place liferaft normally carried in the cabin of the helicopter might not be accessible.

After the raft is removed from its container, it is inflated with a CO_2 cartridge. The survivor then enters the liferaft and orally inflates a set of auxiliary buoyancy tubes to increase the raft's freeboard. Since the boarding procedure necessarily introduces a large quantity of water into the raft, the survivor must bail the water out of the raft with his flight helmet. This procedure usually requires about 3-5 minutes. Once bailed out, the raft provides about 40-50 cm of freeboard in calm water. Figure 13 shows a subject seated within a fully bailed out raft.

During the tests, the rafts were secured to TRIUMPH with a safety line suspended from a boom. The boom was constructed of various lengths of PVC pipe, as described previously (30). Tethering the rafts in this manner prevented them from being carried away from the test site by either the current or the waves.

E. Environmental Conditions

All tests were performed in the Baker Bay region of the Columbia River at U.S. Coast Guard Station Cape Disappointment, WA. Rough seas were created artificially with the wake of a Coast Guard 44-foot (MLB) running at 5 m/sec (9 knots). Wave height was 1.5 m; wave frequency was 1.5-2.0 waves per minute; wave speed was 5 m/sec. Every third wave was a breaking wave. The sea-state created in this manner had previously been shown to simulate a natural rough-sea environment (30).

Figure 13. One-man liferaft

Mean water temperature was 6.1 ± 0.4°C. Mean air temperatures were: dry-bulb, 7.7 ± 1.0°C; wet-bulb, 7.2 ± 1.0°C; black-globe, 9.2 ± 1.4°C. Wind speed was 7.5 - 10 m/sec (15-18 knots) at 1 m from the opening of the ventilation ducting atop the capsized boat. Ambient wind at the test site varied from 0.0 to 2.5 m/sec (0-5 knots). River current was 0.0 to 1.5 m/sec (0-3 knots).

The time of day during which tests were conducted was not constant. In order to minimize variations in water temperature (which fell during flood tides and rose during ebb tides) and in ambient weather conditions, tests were generally conducted during the last two hours of a flood tide. When unacceptably high dry-bulb and/or black-globe air temperatures were encountered, tests were conducted in the pre-dawn or post-sunset hours. Tests were never conducted in direct sunlight. Selecting for tidal conditions to control water temperature and to avoid sunlight necessarily meant varying the start-time for each day's tests. The slight variation in the subjects' initial rectal temperatures produced by this procedure (due to the effects of circadian rhythm) was considered less important than the significant changes in air and water temperatures which would have occurred had the tests been conducted the same time each day. The small circadian rhythm effect was minimized still further by randomizing the order of tests for each subject, garment-ensemble and survival environment.

F. Measurements

Rectal temperatures were measured with a Yellow Springs Instruments (YSI) reuseable thermistor (YSI Model 401) inserted 12 cm from the anus.

A 2 cm length of rubber tubing was situated 10 cm from the thermistor tip so that, following insertion, the tubing lay just within the internal anal sphincter. The tubing thus prevented accidental displacement of the probe.

Skin temperatures were measured from five sites: 1) **Forehead** (at a point midline between the ears and midline between the nose and the hairline); 2) **Arm** (left anterior arm over mid-biceps); 3) **Chest** (left lateral thorax in the mid-axillary line at the level of the nipple); 4) **Thigh** (left anterior thigh, midway between the groin and the knee); 5) **Calf** (left lateral calf, midway between the knee and the heel). Skin temperatures were measured with YSI reuseable surface temperature thermistors (Model 409B). A mean-weighted skin temperature was calculated from the arm, chest, thigh and calf temperatures according to the method of Ramanathan (51).

The rectal and skin temperature thermistor cable leads from each subject were hard-wired into a single, 2 m length of multi-lead, salt-water-proof, polyethylene coated cable. The 2 m cable terminated in a water-proof, multi-pin connector. Ten of these thermistor-cable assemblies (called monitering-harnesses) were constructed, and each of the eight subjects was provided with his own monitering-harness throughout the course of the tests. The water-proof cable was obtained from Whitmore Wire and Cable Co. (Model No. 16878/1), Los Angeles, CA. The water-proof connectors were obtained from Milgray Inc. (Model Nos. MS3476L2221SW and MS3471L2221PW), Marlton, NJ.

The intact and torn Navy dry suits (NI and NX) were specially modified to permit passage of the monitering-harness cable through the

garment without affecting its water-tight integrity. This was accomplished by installation of a gasket in the mid-upper back section of the dry-suit. The gasket was then enclosed within a water-proof, flexible, nylon tube. The thermistor end of the monitering-harness was fed through the nylon tube and gasket to the interior of the garment, allowing a sufficient length of cable to permit easy attachment of the skin and rectal temperature probes. The monitering-harness cable was then tightly secured within the nylon tube by means of a hose-clamp. Finally, the end of the nylon tube was fastened to the cable with water-proof tape. The nylon tube is seen in Figure 8 extending cephalad from the mid-upper back of the garment.

During data recording, each monitering harness was connected to a 30 m length of water-proof cable via the water-proof connector. The 30 m cable was in turn connected to a computerized data-logging system aboard the Coast Guard 52-foot Motor Lifeboat TRIUMPH. The data recording system consisted of the following items of Hewlett Packard (HWP) electronic components: Personal Technical Computer (HWP 9816S) with a 3.5" flexible disk drive (HWP 9121D); digital voltmeter (HWP 3456A); signal scanner (HWP 3495A); two-pin plotter (HWP 7470A); and a thermal graphics printer (HWP 2671A). Rectal and skin temperatures were obtained every minute from each test subject. In addition, water temperature and dry-bulb air temperature were obtained every minute. Wet-bulb and black globe air temperatures were obtained every ten minutes.

Subjective evaluations of garment-ensemble performance were obtained from each subject after each test. The amount of cold-water

flushing or leakage, the degree of protection from wind and spray, and the degree of comfort provided were each scored on a scale from 1 (least) to 10 (most). Flushing/leakage of cold water was evaluated only for the water-immersion, rough-sea environment; protection against wind and spray was evaluated only for the boat and raft environments. The degree of comfort of the garment-ensembles was evaluated for all three survival environments.

The amount of water leakage into NI and NX was determined by the difference in combined weight of the subject and garment before and after the tests. A correction was made for the small amount of water retained on the outer surface of the dry suits. No supplemental equipment was worn during the weighing procedures (i.e. flight helmet, gloves, boots, PFD, etc. were all removed). Weights were obtained on a calibrated, medical beam-balance.

G. Procedures

The procedural design of this study was intended to simulate, as realistically as possible, the various survival environments faced by crewmen of a capsized vessel or ditched helicopter in rough seas. A helicopter invariably capsizes in rough water due to the combined weight of engines, transmission and rotor-blades positioned high above its center of mass (52). Certain types of helicopters, however, are capable of floating in an inverted attitude. Figure 14 shows a capsized Coast Guard HH-3F helicopter following a ditching in which only one of the crewmen successfully escaped.

A survivor of either a vessel or helicopter capsizing usually makes

Figure 14. Capsized helicopter in rough seas

an underwater escape from an enclosed compartment. Once on the surface, he inflates his PFD (if available) and then selects from among the possible environments (in the water, atop the capsized vessel or helicopter, or in a liferaft) the one offering the best chance for survival. In the procedures described below, this sequence of events was closely simulated.

Approximately 90 minutes before the start of each test (t= -90 min), the subjects arrived at the shoreside laboratory at Coast Guard Station Cape Disappointment to begin instrumentation and dressing procedures. Rectal temperature thermistors were inserted, skin temperature thermistors were attached with waterproof tape, and the garment-ensembles were donned. In order to prevent heat accumulation within the garments prior to the start of the tests, the garments were worn loosely (e.g. zippers were left open, hoods were not deployed, etc.). Temperature readings were then taken on each subject to ensure proper performance of the thermistors. At approximately t= -20 min, the subjects were transported to the boat docks for transfer to the test site. At the boat docks, subjects wearing either NI or NX were weighed, and all subjects configured their garment-ensembles for maximum protection (i.e. zippers were closed; hoods and beaver tails were deployed; helmets, PFDs, gloves, etc. were donned). The subjects were then transported to the test site aboard a Coast Guard 44-foot MLB.

At the test site the subjects' monitering harnesses were attached to the computer via their respective water-proof sensor cables. Five minutes of pre-test recordings were obtained to ensure proper function of the data-collection system. At t= -5 min, the subjects were

transported to the test platform aboard a Coast Guard 6 m, rigid-hull, inflatable (RHI) rescue boat.

At t=0, all subjects entered the water and data collection was started. At t=20 seconds and again at t=40 seconds, the subjects immersed their heads underwater for 10 seconds to ensure thorough wetting under their helmets and/or hoods (simulating underwater egress from a capsized boat or helicopter). At t=1 min, the subjects inflated their PFDs. At t=5 min, subjects scheduled for exposure to wind, spray and breaking waves climbed atop the capsized-boat test platform and seated themselves near the bow, 1 m from the opening of the ventilation ducting. The fans and sprinkler system were then activated. Also at t=5 min, subjects scheduled for exposure to cold air and waves in the one-man liferafts boarded the inflated rafts. They then orally inflated the auxiliary buoyancy tubes and bailed the water out of the rafts. Finally, subjects scheduled for exposure to rough seas remained in the water next to the test platform. At t=6 min, wave-making procedures were started.

Figures 15 and 16 show the effects of a breaking wave on subjects in the water. Each breaking wave totally immersed the subjects, and the vertical motion induced by both the wave and its backwash from the test-platform insured maximal flushing of water in the garment-ensembles. Figure 16 shows the relative size of a breaking wave with respect to the subjects in the water. Note that one subject is totally immersed (only his hands are visible) while the other subject is about to be immersed.

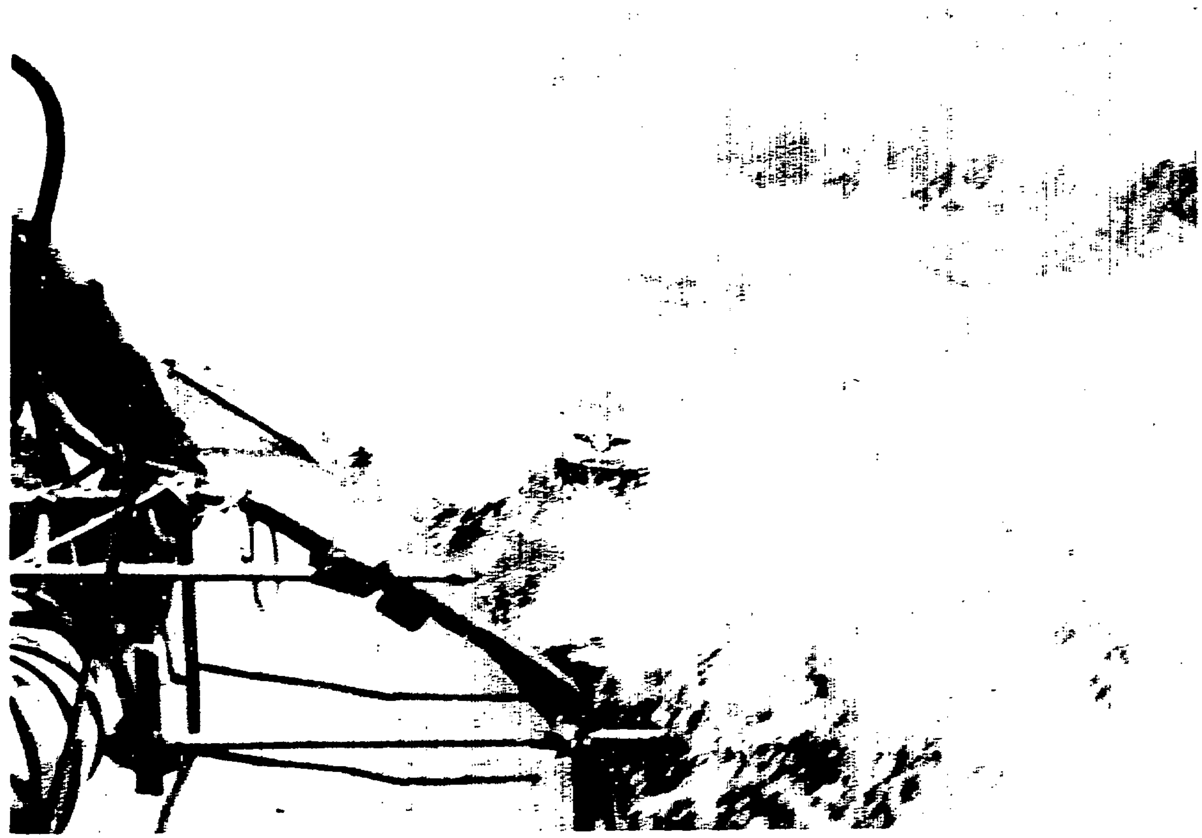

Figure 15. Wave breaking on subject immersed in rough seas

Figure 16. Wave breaking over two subjects immersed in rough seas. Subject in the center of the photograph is totally submerged (only his hands are visible); the other subject is about to be submerged.

Figures 17 and 18 show the effects of breaking waves on subjects seated on the test-platform. The waves were not large enough to totally immerse these subjects; rather, they struck the subjects on the trunk between the waist and the top of the shoulders. Figure 17 shows a wave totally immersing the subjects in the water and about to strike the subject on the boat at mid-chest. Figure 18 shows a wave just at the point of impact on the subject seated on the test-platform.

Figure 19 shows the effects of a breaking wave on subjects in the one-man liferaft. Note the subject on the left is able to ride atop the wave, while the subject on the right is struck by the wave.

A subject's test was terminated for any of the following reasons: 1) voluntary request for cessation; 2) rectal temperature decline to 35°C; 3) two hours elapsed time; 4) medical officer order for cessation. Following termination of a test, the sensor cable was detached from the subject's monitering harness and he was transported to the boat docks aboard the RHI. Weighing procedures were performed (for NI and NX only), and the subject was then transported to the rewarming area.

Two methods of rewarming were used: 1) 5-10 minutes in a sauna at 65°C, followed by 2) 30-45 minutes in a circulating hot-water bath at 38°C. Throughout the entire recovery procedure, the subjects were continuously monitored by medical personnel, and rectal temperatures were continuously recorded.

The following safety procedures were used during all cold-exposure tests: 1) every subject was fitted with a rescue line attached to TRIUMPH; 2) every garment-ensemble had buoyancy ranging from 6.6 to 30 kg; 3) a 6 m RHI rescue boat, manned by an experienced coxswain and at

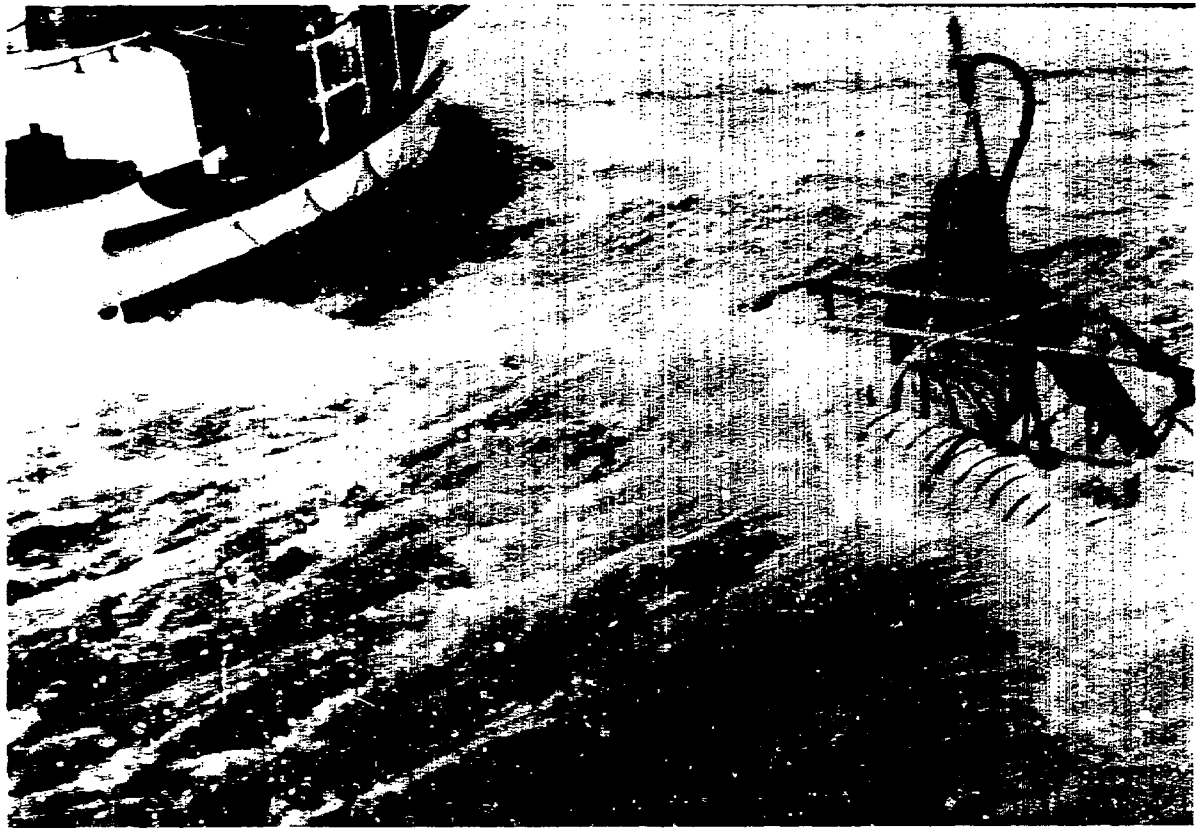

Figure 17. Wave breaking on subject atop capsized boat. Subjects in the water are completely submerged.

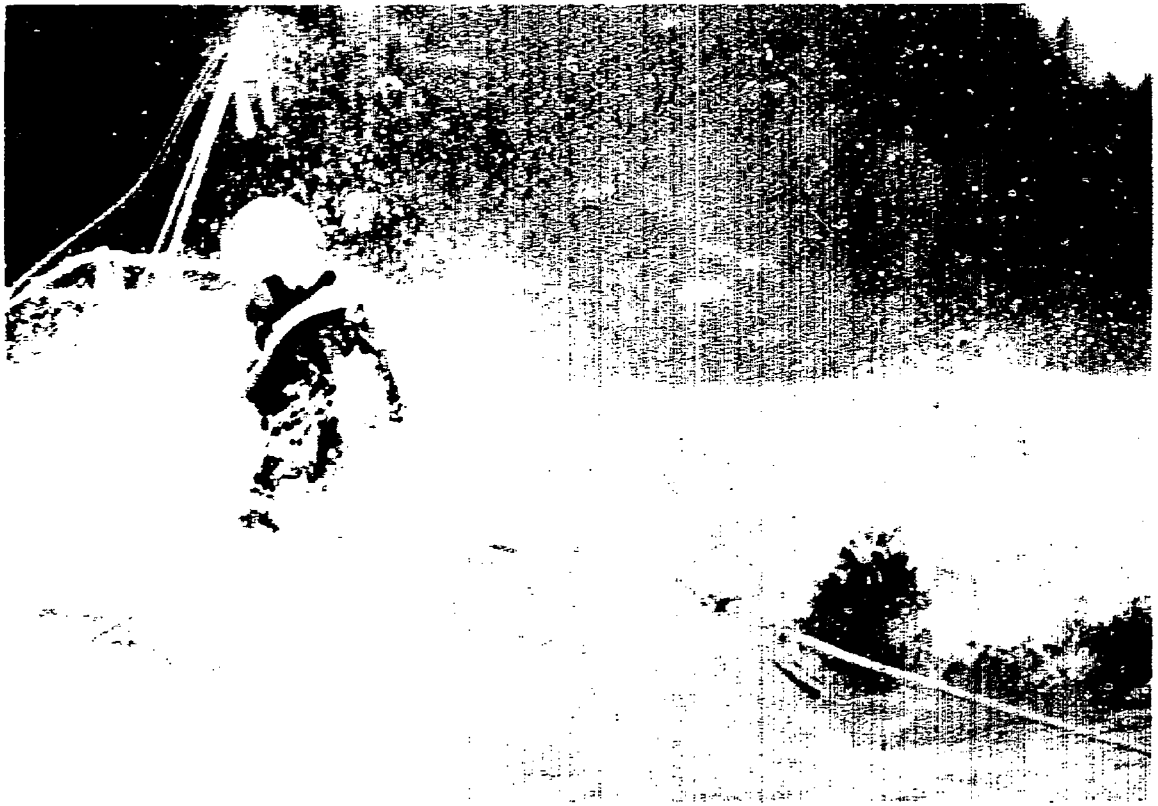

Figure 18. Wave breaking on subject atop capsized boat

Figure 19. One-man liferaft in rough seas

least one rescue crewman, was stationed in the test area; 4) a medical officer was stationed either in the water, atop the test platform or aboard TRIUMPH; 5) advanced cardiac life-support equipment was available aboard TRIUMPH and in the rewarming area.

H. Statistical Analysis

Randomization of the 8 subjects and the 15 combinations of garment-ensemble and environment was accomplished via a nested technique with constraints. A regular "grid" of environments/day (e.g. water, boat or raft) and number of tests/environment/day was established for the testing period. First the environment "slots" were randomly seeded with garment-ensembles; then the resulting garment-environment "slots" were randomly seeded with subjects. Operational constraints on allocation of subjects, garment-ensembles and environments were as follows: 1) subjects could be tested only once per day, in order to ensure reequilibration of physiologic homeostasis between tests; 2) subjects could be tested only once per combination of garment-ensemble and environment; 3) no more than two subjects/day could be tested on the boat because of space limitations; 4) no more than two subjects/day could be tested in the rafts because of limitations in raft availability; and 5) no more than two dry suits (NI and/or NX) per day could be tested because of limitations in preparation time.

The units of variation for inter-environment and inter-garment comparisons were as follows: 1) time-to-onset-of-cooling; 2) linear cooling rate; 3) final cooling rate; 4) decline in mean-weighted skin

temperature (MWST) during the first five-minutes of cold-exposure; and 5) decline in MWST over the duration of cold-exposure. Duration of exposure was calculated but was not used in statistical comparisons because termination of a subject's exposure was occasionally for reasons of safety or for medical considerations rather than for garment-ensemble performance (e.g. rectal temperature = 35°C). Similarly, subjective evaluations of garment-ensemble performance in each environment were tabulated but were not used in statistical comparisons because of the possibility of subject bias for or against certain of the garment-ensembles.

Time to onset of cooling was defined as the time at which rectal temperature declined 0.25°C from the highest temperature reached after initial cold exposure. Linear cooling rate and final cooling rate were calculated from a selected segment of the rectal temperature curve beginning at the time-to-onset-of-cooling and ending 3 minutes prior to the last reliable measurement. The final 3 minutes were deleted from the cooling curve to minimize the variation in temperature which occurred during preparations for termination of cold exposure.

Linear cooling rate was obtained from the slope of the selected segment of the rectal temperature curve. A simple linear regression model of time on rectal temperature was initially used to obtain the slope. However, a significant degree of first-order serial correlation was observed in the residuals from this regression fit for all of the rectal temperature curve segments ($p < 0.05$ for the Durbin-Watson statistic, which tests the null hypothesis that first-order serial correlation of the residuals is absent (75)). This first-order serial

correlation is typical of well-behaved temperature cooling curves (76). Since slope estimates and their standard errors can be biased by the presence of serial correlation in the residuals, the rectal temperature curve segments were refitted with a first-order serial correlation error term included in the linear regression model (77). All of the resulting augmented models showed a significant reduction in or absence of serial correlation in the residuals. All estimated slopes were statistically significant ($p < 0.015$), with an average r^2 of 0.9948. These slopes were subsequently used as estimates of rectal temperature cooling rates for individual subjects within combinations of garment-ensemble and environment.

Final cooling rate was calculated from the slope of the final minute of the selected segment of the rectal temperature cooling curve. Because slight curvature could be discerned graphically in many of the rectal temperature curve segments used for analysis, a full quadratic regression model of time and time-squared on rectal temperature, including a first-order serial correlation error term, was fitted for each segment. Significant reduction in or absence of serial correlation in the residuals was again observed in all of the quadratic models. The quadratic term was statistically significant ($p< 0.05$) in 65% of the rectal temperature curve segments, with an average r^2 for all models of 0.9954. The instantaneous slope at the endpoint for each rectal temperature curve segment was calculated using the first derivative of the structural part of the quadratic model.

Declines in MWST during the first 5 minutes of exposure and over the duration of exposure were calculated as follows from the curves of

MWST vs time. Two points and one segment from each individual MWST curve were selected for analysis. The two points were located at 0 minutes (e.g. initial MWST) and 5 minutes, and the segment began at 5 minutes and ended 3 minutes prior to the last reliable temperature measurement for that curve. Decline in MWST during the first 5 minutes of cold exposure was simply calculated as the difference between the observed MWST at 0 and 5 minutes. Decline in MWST over the duration of exposure was calculated as the difference between the MWST at 0 minutes and the mean of all MWSTs from 5 minutes to the end of the selected MWST curve segment.

Paired t-tests were used to evaluate inter-environment differences (water vs boat, water vs raft, and boat vs raft) within each garment-ensemble for time-to-onset-of-cooling, linear cooling rate, decline in MWST during the first 5 minutes of exposure, and decline in MWST over the duration of exposure. Paired t-tests were also used to evaluate the difference between linear cooling rate and final cooling rate. For all paired t-tests, subjects were paired with themselves across environments. Boxplots and quantile plots (78) of the differences from each comparison did not indicate the presence of significant outliers or serious non-normality.

A randomized, complete block design (79) was used to assess inter-garment differences within each environment. Subjects were aligned with themselves as blocks across garments. Multiple linear regression was used to obtain all pairwise contrasts, their standard errors, estimated missing values, and adjusted covariance matrices (79). Tukey's test for multiple comparisons (79) was used to evaluate pairwise contrasts for

time-to-onset-of-cooling, linear cooling rate, decline in MWST during the first 5 minutes of exposure, and decline in MWST over the duration of exposure. Diagnostic plots indicated both an adequate fit and well-behaved residuals for all these variables except linear cooling rate. For linear cooling rate, boxplots, residual-vs-predicted plots, and residual-quantile plots (80) all indicated the presence of outliers and heteroscedasticity in each environment tested. Since garment variances tended to be proportional to the magnitude of garment means, linear cooling rate was re-analyzed with a logarithmic transformation (75). This produced a more reasonable fit with well-behaved residuals.

Survival times in water for each subject in each garment-ensemble were calculated using both the estimated linear rectal temperature cooling rate and the decrease in rectal temperature associated with the time-to-onset-of-cooling. The time-to-onset-of-cooling was added to a linear extrapolation of time to points representing overall hypothetical decreases in rectal temperature (37.5°C decreasing to 34, 30 and 25°C). Simultaneous confidence intervals for each garment-ensemble were constructed using the error estimate from a randomized, complete block ANOVA of survival times and from Tukey's multiple comparison adjustment. Heteroscedasticity again justified the use of the log-transformation of survival times in order to obtain accurate confidence intervals.

The distribution and magnitude of several potential covariates were examined both graphically and analytically. The covariates included daily minute-by-minute air and water temperatures averaged over the course of each test, absolute day number of each test, time of day of

each test, and baseline rectal and MWSTs for each test. For each covariate, inter-environment comparisons within garment-ensembles and inter-garment-ensemble comparisons within environments were made with the use of previously described t-tests and ANOVAs.

The results of covariate analysis indicated that randomization had generally achieved a relatively adequate balance in the location and scale of uncontrolled variability. Partial loss of randomization, from scheduling changes necessitated by weather, occurred for test day number during the last 20% of the testing period. Overall, the few statistically significant, inter-environment, covariate t-tests which were found could all be dismissed on the basis of clinically insignificant magnitudes of difference. Significant differences among garments were observed only for the baseline MWST covariate, reflecting the differences in actual protection provided by each garment-ensemble within a particular environment. No attempt was made to adjust for these differences as they were considered part of the basis for establishing the relative protection provided by the garments in each environment.

RESULTS

A. Rectal Temperature Changes

Figures 20-22 show the composite rectal temperature cooling curves for selected subjects for the various garment-ensembles in the water, boat and raft environments, respectively. These subjects' responses were representative for the particular environment depicted. The figures demonstrate the shapes of the various cooling curves and permit a visual comparison of typical rectal temperature responses both among

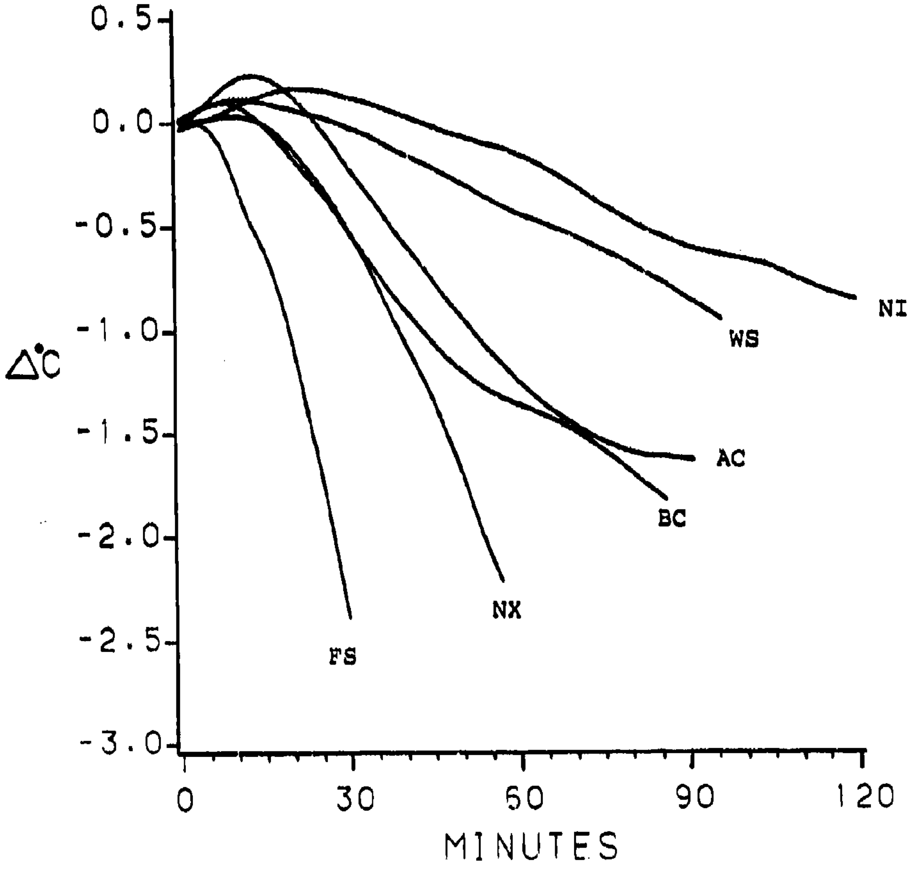

Figure 20. Rectal temperature change for subject 8 wearing each of the garment-ensembles in rough seas.

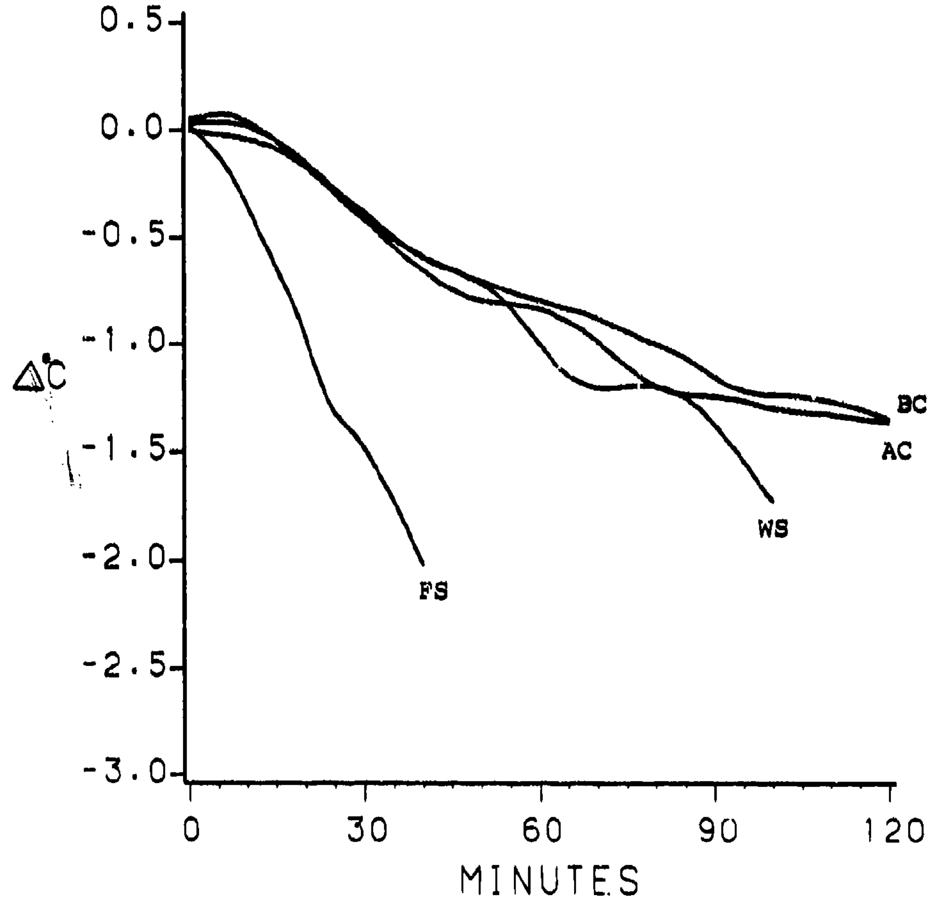

Figure 21. Rectal temperature change for subject 7 wearing each of the garment-ensembles on the boat.

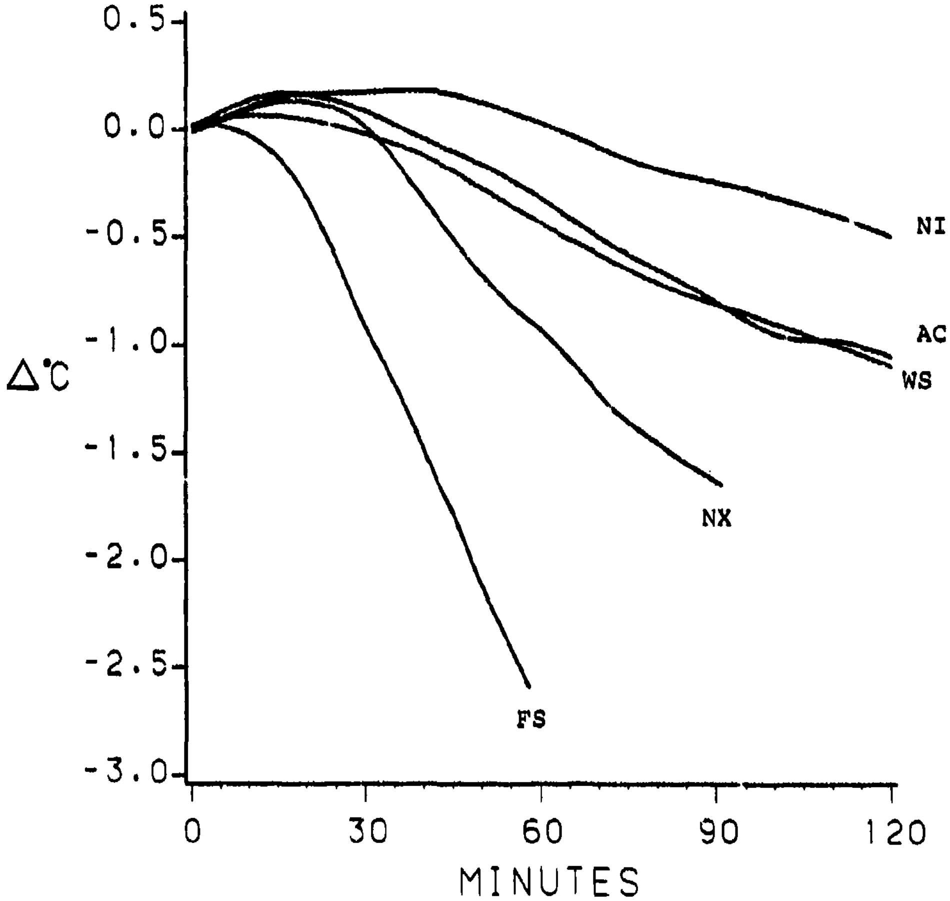

Figure 22. Rectal temperature change for subject 6 wearing each of the garment-ensembles in the liferaft.

garment-ensembles and between environments. Figures 23-25 show the complete set of rectal temperature cooling curves for all subjects in the three survival environments. These figures demonstrate the variation among subjects for each garment-ensemble in each environment (reading horizontally across rows) and the variation among garment-ensembles for each subject in each environment (reading vertically down columns).

The cooling curves have the following general characteristics: 1) a variable amount of temperature rise after t=0, followed by a decline over the remaining duration of exposure; 2) a linear rate of decline after the onset of cooling (with onset of cooling defined as a drop of 0.25°C from the maximum temperature reached after t=0); and 3) a variable change in cooling rate during the latter minutes of exposure (with a final cooling rate calculated during the final minute of exposure). Figure 26 illustrates these parameters of the cooling curves.

Table 3 shows the mean time-to-onset-of-cooling for the various garment-ensembles and survival environments. A wide variation occurred in this parameter among garments-ensembles within each environment. FS allowed the fastest onset of cooling and NI permitted the slowest onset of cooling in all environments. AC and BC showed similar times to onset of cooling in both the water and boat environments, but each allowed a faster onset of cooling than WS in all environments. NX allowed the slowest onset of cooling for all garment-ensembles except NI. Between environments, times to onset of cooling were generally greatest for

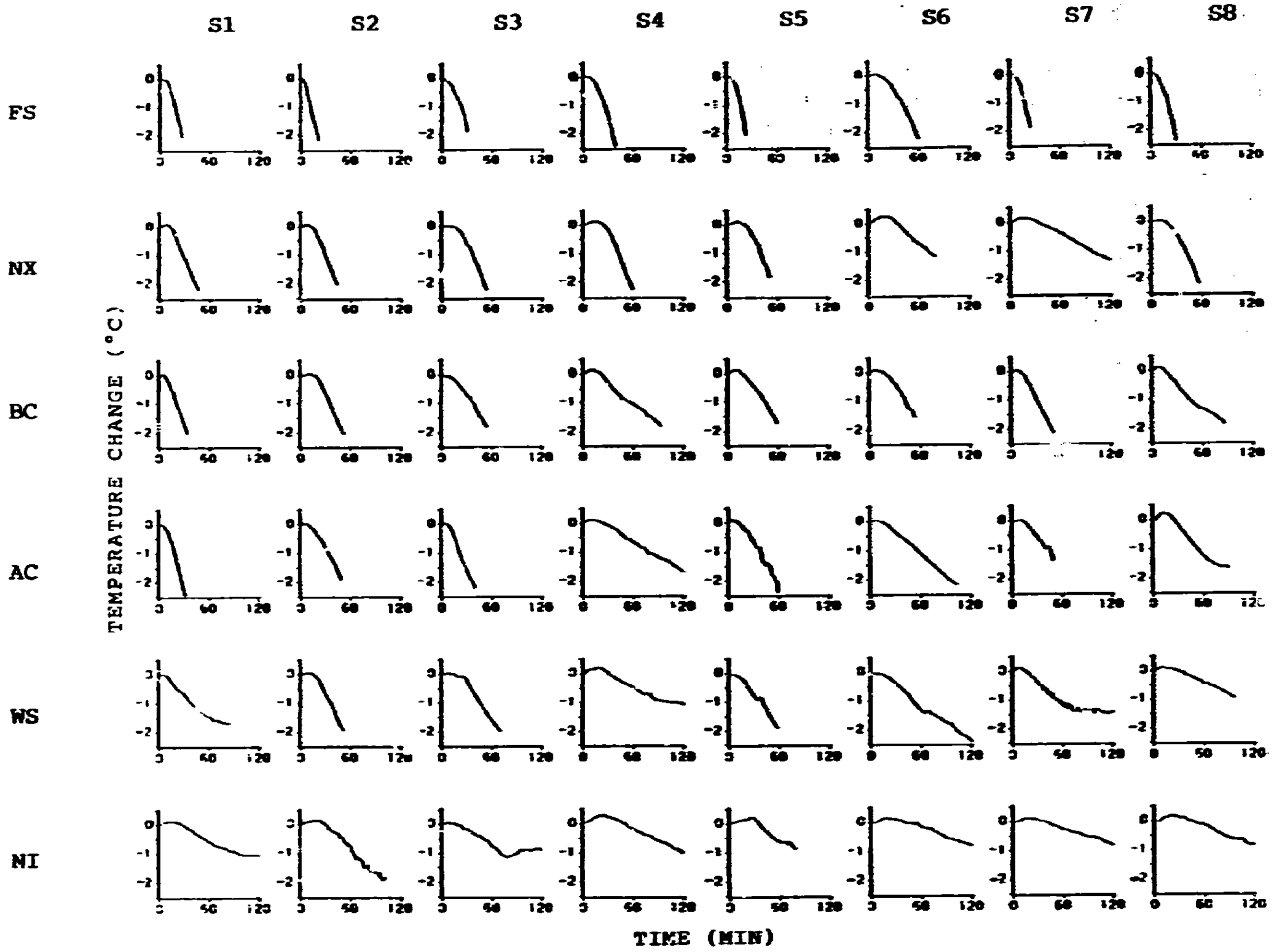

Figure 23. Rectal temperature change for each subject (columns) in each garment-ensemble (rows) in rough seas.

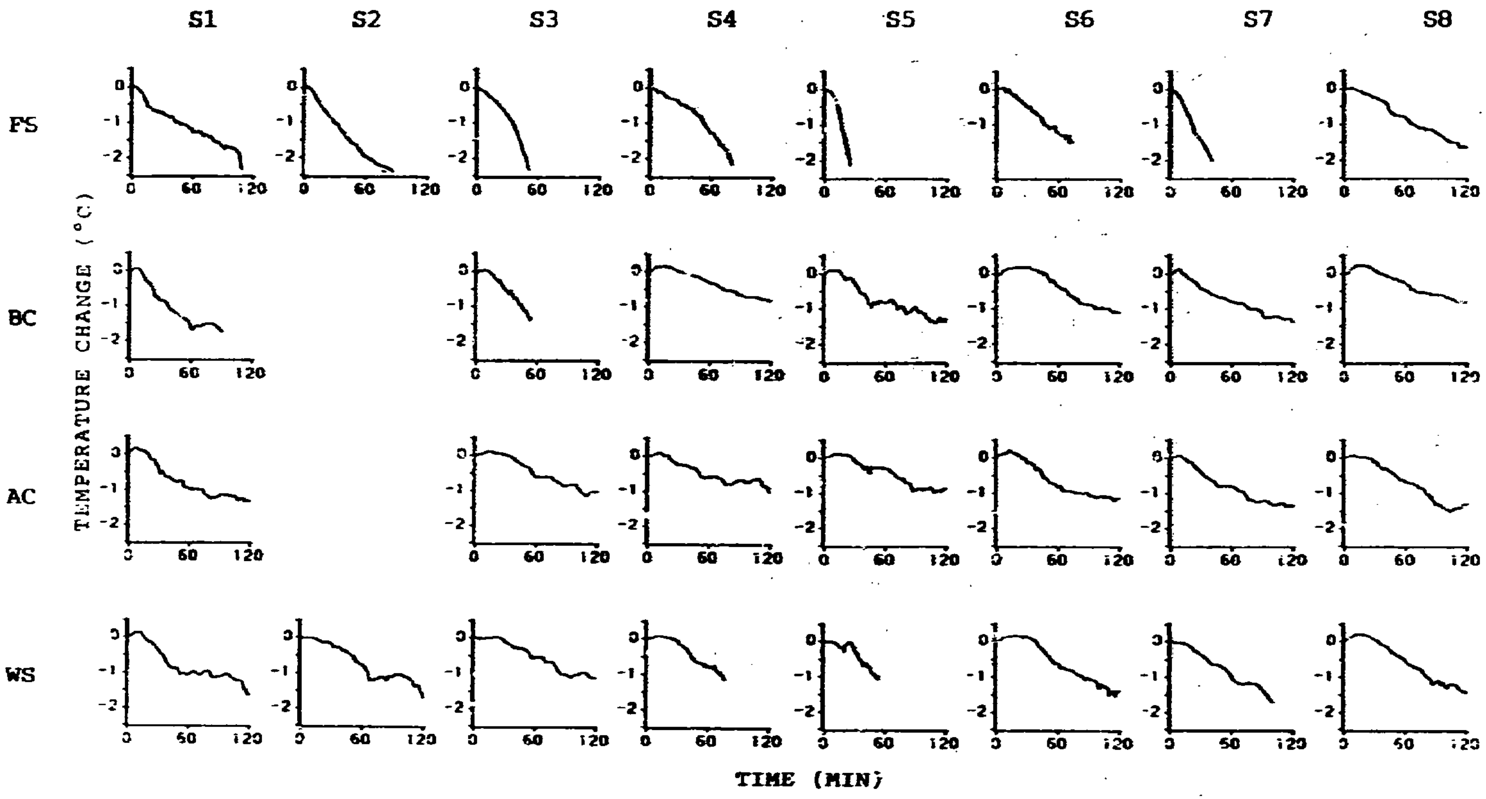

Figure 24. Rectal temperature change for each subject (columns) in each garment-ensemble (rows) on the overturned boat. (Blank spaces indicate missing data).

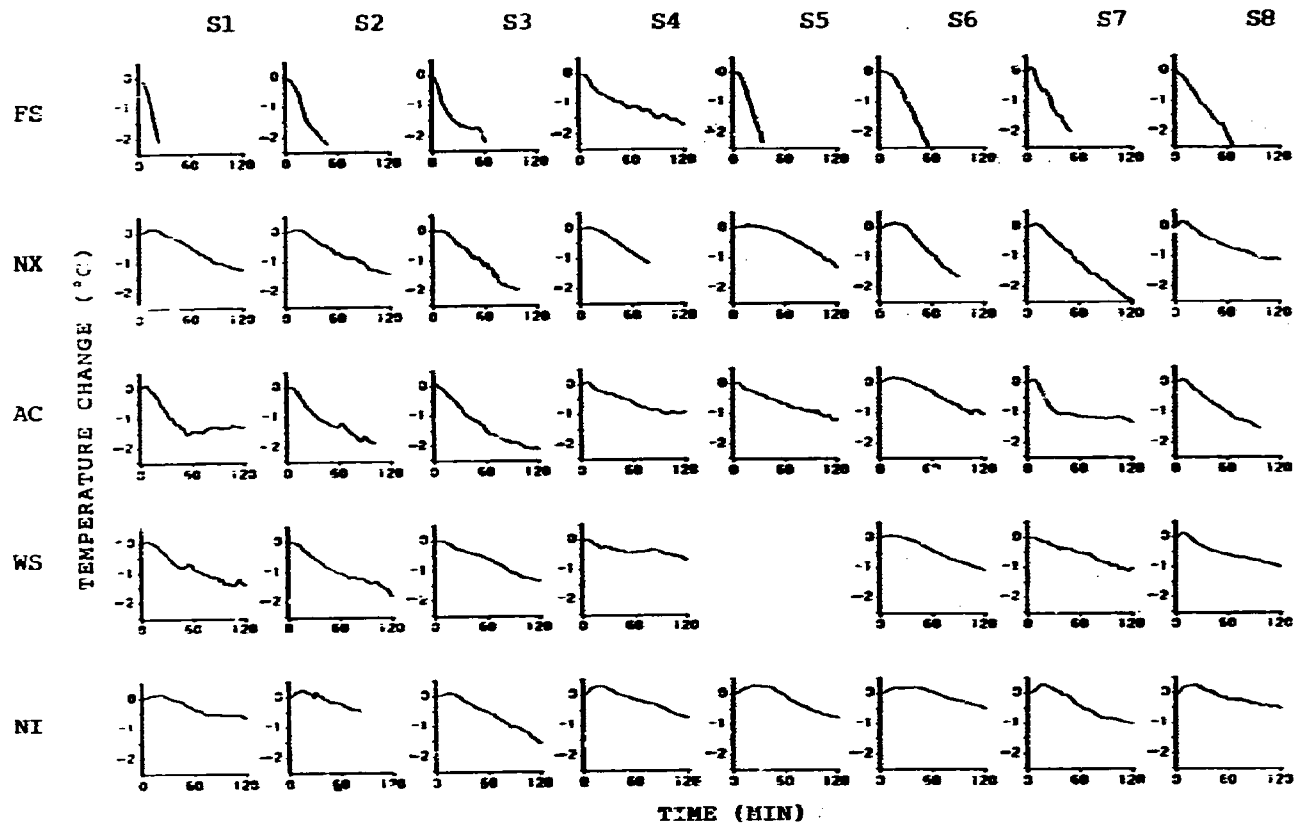

Figure 25. Rectal temperature change for each subject (columns) in each garment-ensemble (rows) in the one-man liferaft. (Blank space indicates missing data.)

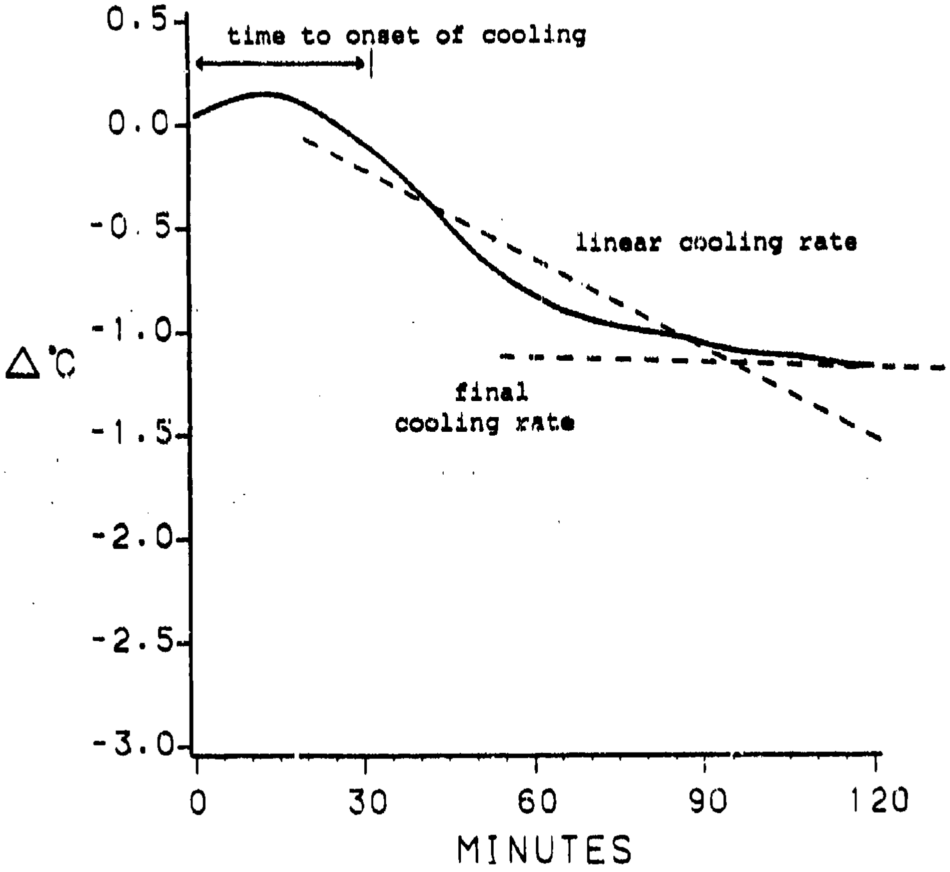

Figure 26. Sample curve of rectal temperature change illustrating parameters of 1) time to onset of cooling; 2) linear cooling rate; and 3) final cooling rate.

Table 3. Mean Time-to-Onset-of-Cooling*

Garment-Ensemble	Time (min) (mean ± SEM)
Water	
Flight Suit (FS)	11.0 ± 3.9
Aircrew Coverall (AC)	19.3 ± 4.5
Boatcrew Coverall (BC)	19.5 ± 1.7
Wet Suit (WS)	23.9 ± 2.8
Navy Dry Suit (torn) (NX)	25.3 ± 2.7
Navy Dry Suit (intact) (NI)	42.5 ± 3.6
Boat	
Flight Suit	13.1 ± 2.2
Aircrew Coverall	28.1 ± 2.3
Boatcrew Coverall	29.1 ± 5.0
Wet Suit	31.5 ± 2.5
Raft	
Flight Suit	9.6 ± 1.2
Aircrew Coverall	17.9 ± 3.3
Wet Suit	25.0 ± 3.5
Navy Dry Suit (torn)	29.3 ± 3.6
Navy Dry Suit (intact)	43.9 ± 4.1

*Onset of cooling is defined as a decline of 0.25°C from the maximum temperature reached after t=0.

Vertical bars indicate groups of garment-ensembles with statistically similar results (per Tukey's multiple comparison test (alpha = 0.01).

water immersion and slowest for exposure to wind and spray atop the overturned boat. Exceptions to this were the slightly faster times to onset of cooling of subjects wearing FS and AC in the raft than in the water environment. A statistically significant difference in time to onset of cooling was only found for the wet suit between the water and boat environment ($p = 0.012$).

Table 4 shows the mean duration of cooling for the subjects wearing each of the garment-ensembles in each of the survival environments. Of the total number of cold-exposures in this study, 10 (9%) were terminated prematurely for medical reasons (muscle cramps, etc.) or at the direction of the attending medical officer. The remainder lasted the full exposure period or were terminated for low core temperature. In the water-immersion environment, FS allowed the shortest and NI allowed the longest duration of cooling. AC, BC and NX each permitted approximately an hour of cold exposure, and WS allowed approximately ninety minutes of cooling. For subjects exposed to wind and spray on the overturned boat, FS again allowed the shortest duration of cooling, but this was nearly two and one half times its value for water immersion. The other garment-ensembles each allowed over 100 min of cold exposure. For the raft environment, FS allowed slightly less than a one hour duration of cooling. This was about twice the value for FS in the water, but it was only about half the duration of exposure of any of the other garment-ensembles in the raft.

Figure 27 and Tables 5-7 show the mean rectal temperature cooling rates of the subjects for each of the garment-ensembles in the three survival environments. The tables show not only the mean linear cooling

Table 4. Mean Duration of Cooling*

Garment-Ensemble	Time (min) (mean ± SEM)
Water	
Flight Suit (FS)	31.6 ± 4.5
Aircrew Coverall (AC)	67.9 ± 11.5
Boatcrew Coverall (BC)	60.8 ± 6.9
Wet Suit (WS)	90.3 ± 10.0
Navy Dry Suit (torn) (NX)	63.9 ± 8.8
Navy Dry Suit (intact) (NI)	112.9 ± 5.2
Boat	
Flight Suit	73.4 ± 11.7
Aircrew Coverall	120.0 ± 0.0
Boatcrew Coverall	106.4 ± 9.6
Wet Suit	103.9 ± 10.4
Raft	
Flight Suit	57.9 ± 10.3
Aircrew Coverall	114.6 ± 3.5
Wet Suit	120.0 ± 0.4
Navy Dry Suit (torn)	108.4 ± 6.0
Navy Dry Suit (intact)	115.4 ± 4.6

*Cooling was terminated for any of the following reasons: 1) rectal temperature = 35°C
2) 120 min exposure
3) at the request of the subject
4) at the direction of the physician

rate over the duration of cold exposure but also the final cooling rate during the last minute of exposure and the p-values for the differences between these two cooling rates. Finally, Table 8 shows the p-values for comparison of mean linear cooling rates between environments for each of the garment-ensembles.

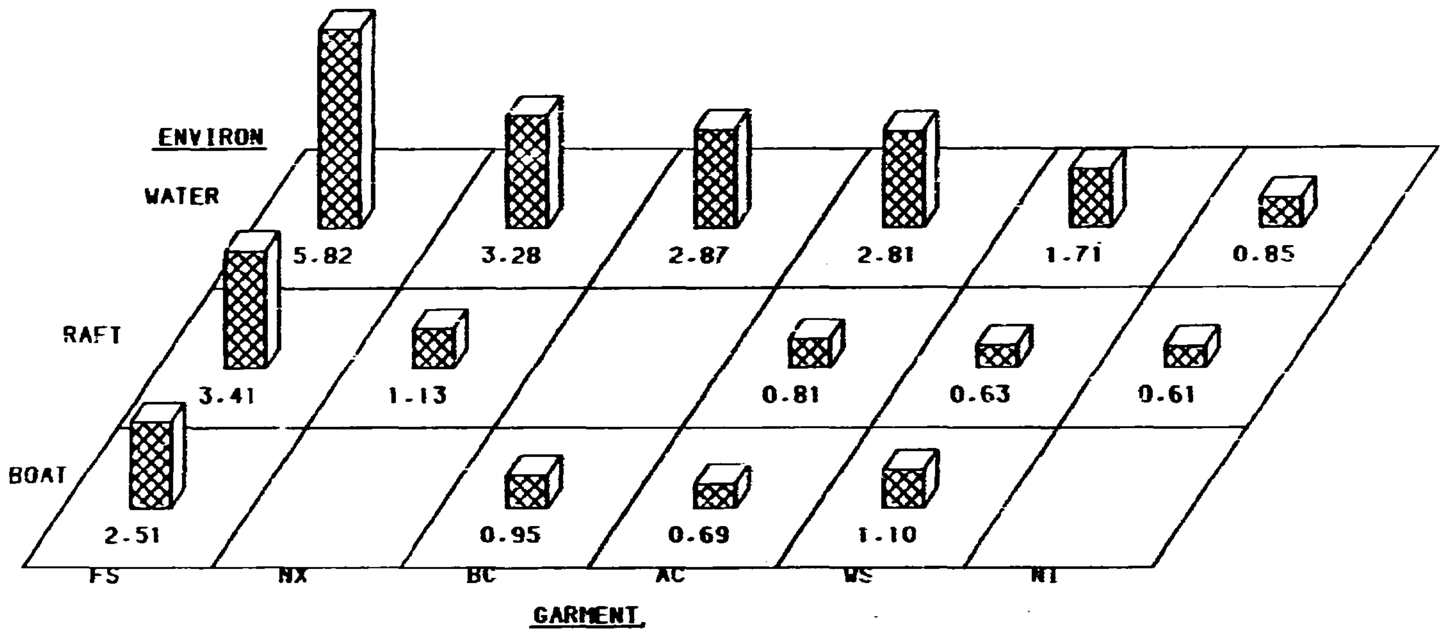

Figure 27. Mean linear cooling rate for each garment-ensemble in each survival environment. Blank squares indicate combinations of garment-ensemble and environment which were not tested.

Table 5. Cooling Rates for Garment-Ensembles in Rough Water

Garment	Mean Linear Cooling Rate* (°C/hr ± SEM)	Final Cooling Rate** (°C/hr ± SEM)	p
FS	5.83 ± 0.52	9.77 ± 1.15	.007
NX	3.28 ± 0.45	4.69 ± 0.95	.061
DC	2.87 ± 0.39	3.18 ± 0.64	.446
AC	2.81 ± 0.62	2.82 ± 1.11	.987
WS	1.71 ± 0.37	1.16 ± 0.62	.171
NI	0.86 ± 0.15	-0.07 ± 0.35	.021

*Calculated from time of initial 0.25°C decline in rectal temp. to end of exposure.

**Cooling rate during last minute of exposure.

p-values are from paired t-tests of the difference between mean linear and final cooling rates.

Vertical bars indicate groups of garment-ensembles with statistically similar mean linear cooling rates (per Tukey's multiple comparison test, alpha = .01).

Table 6. Cooling Rates for Garment-Ensembles In Wind, Spray and Waves Atop The Overturned Boat

Garment	Mean Linear Cooling Rate* (°C/hr ± SEM)	Final Cooling Rate** (°C/hr ± SEM)	p
FS	2.52 ± 0.52	2.76 ± 1.02	.656
WS	1.10 ± 0.15	0.20 ± 0.64	.009
BC	0.95 ± 0.16	0.04 ± 0.47	.050
AC	0.70 ± 0.05	-0.26 ± 0.14	.002

*Calculated from time of initial 0.25°C decline in rectal temp. to end of exposure

**Cooling rate during last minute of exposure.

p-values are from paired t-tests of the difference between mean linear and final cooling rates.

Vertical bars indicate groups of garment-ensembles with statistically similar mean linear cooling rates (per Tukey's multiple comparison test, alpha = .01).

Table 7. Cooling Rates for Garment-Ensembles In The One-Man Liferaft

Garment	Mean Linear Cooling Rate* (°C/hr ± SEM)	Final Cooling Rate** (°C/hr ± SEM)	p
FS	3.42 ± 0.72	2.96 ± 1.36	.571
NX	1.14 ± 0.13	0.71 ± 0.19	.029
AC	0.82 ± 0.09	-0.15 ± 0.23	.004
WS	0.64 ± 0.07	0.31 ± 0.12	.081
NI	0.62 ± 0.07	0.14 ± 0.23	.057

*Calculated from time of initial 0.25°C decline in rectal temp. to end of exposure.

**Cooling rate during last minute of exposure.

p-values are from paired t-tests of the difference between mean linear and final cooling rates.

Vertical bars indicate groups of garment-ensembles with statistically similar mean linear cooling rates (per Tukey's multiple comparison test, alpha = .01).

Table 8. Comparison by Paired t-Test of Mean Linear Cooling Rates for Garment-Ensembles in Different Survival Environments

Garment Ensemble	p-value
Water vs Boat	
Flight Suit (FS)	.003
Aircrew Coveralls (AC)	.024
Boatcrew Coveralls (BC)	.004
Wet Suit (WS)	.176
Water vs Raft	
Flight Suit	.012
Aircrew Coveralls	.013
Wet Suit	.037
Navy Dry Suit (intact) (NI)	.199
Navy Dry Suit (torn) (NX)	.005
Boat vs Raft	
Flight Suit	.371
Aircrew Coveralls	.293
Wet Suit	.048

For subjects wearing FS in cold, rough seas, the mean linear cooling rate was 5.83°C/hr, which increased to 9.77°C/hr by the end of the exposure period. This difference was statistically significant ($p=.007$). In contrast, for subjects wearing FS on the boat or in the raft, mean linear cooling rates were considerably slower (2.52°C and 3.42°C, respectively), and final cooling rates during the last minute of exposure were not significantly different from mean linear cooling rates. Mean linear cooling rates for FS were significantly faster in the water than on the boat or in the raft ($p=0.003$ and $p=0.012$, respec-

tively); mean linear cooling rate was not significantly different between the boat and raft environments.

For subjects wearing either the AC or BC ensemble in cold rough seas, mean linear cooling rates were about 2.8°C/hr, or slightly less than half that of FS in the water. The final cooling rates for these coveralls were not significantly different from their mean linear cooling rates. For subjects wearing AC or BC in the wind, spray and wave environment of the overturned boat, mean linear cooling rates were considerably smaller than they were in the water (0.70°C/hr and 0.95°C/hr, respectively). These differences were both statistically significant ($p=0.024$ and $p=0.004$, respectively). Furthermore, the final cooling rates for these coveralls were much smaller on the boat than were the mean linear cooling rates. For AC, in fact, the subjects were actually rewarming (mean final cooling rate = -0.26°C/hr) during the last minute of exposure. For subjects wearing AC in the raft, similar results were found. Mean linear cooling rate was much slower than for AC in the water (0.62°C/hr versus 2.81°C/hr), and the final cooling rate again showed a rise in temperature (-0.15°C/hr). Differences in mean linear cooling rates between the water and boat environments were significant for both AC and BC ($p=0.024$ and $p=0.004$, respectively). For AC, mean linear cooling rates were significantly faster in the water than in the raft ($p=0.014$), but not in the raft versus on the boat ($p=0.293$).

For subjects wearing WS in the water, mean linear cooling rate was 1.71°C/hr, which slowed to 1.16°C/hr during the last minute of exposure. This difference was not significant, however ($p=0.171$). For subjects wearing WS on the boat or in the raft, mean linear cooling rates

(1.10°C/hr and 0.64°C/hr, respectively) were slower than in the water, but again the differences were not statistically significant ($p=0.176$ and $p=0.048$, respectively). Final cooling rates for subjects wearing WS on the boat or in the raft were considerably slower than were mean linear cooling rates. This was significant for the boat ($p=.009$) but not for the raft ($p=.081$).

Subjects wearing NI in the water had the slowest mean linear cooling rate among all garment-ensembles in this environment (0.86°C/hr). Subjects wearing NX in the water, however, had a mean linear cooling rate nearly four times faster (3.28°C/hr). Final cooling rate for subjects in the water in NI was significantly slower (-0.07°C/hr, $p=.021$) than was mean linear cooling rate. In contrast, final cooling rate for subjects in the water in NX was faster (4.69°C/hr, $p=.061$) than was mean linear cooling rate. Subjects wearing NI in the raft again had the slowest mean linear cooling rate among all garment-ensembles in this environment (0.62°C/hr). Final cooling rate was even slower (0.14°C/hr), but the difference was not significant ($p=.057$). Subjects wearing NX in the raft had a mean linear cooling rate of 1.14°C/hr. This was approximately one third the value of FS in the raft but about twice that of NI in the raft. Final cooling rate for NX in the raft was 0.71°C/hr ($p=0.29$). Mean linear cooling rate for NI was not significantly different between water and raft environments ($p=0.20$), but for NX, the difference was highly significant ($p=0.005$).

B. Skin Temperature Changes

Figures 28-30 demonstrate the types of change in mean weighted skin temperature which occurred for selected subjects in various garment-ensembles and survival environments. These curves illustrate the typical response of the subjects' skin temperatures to sudden immersion in cold water and subsequent prolonged exposure to rough seas or to sudden immersion in cold water and subsequent exposure to cold wind, spray, etc. on the boat or in the liferaft.

Figure 28 illustrates the pattern of response for subjects wearing FS, BC, AC, WS or NX in the water. Mean weighted skin temperature declined precipitously during the first few minutes of immersion and remained at low levels throughout the duration of the subjects' exposure.

Figure 29 illustrates the pattern of response for subjects wearing NI in the water. Mean weighted skin temperature declined only a few degrees during the first few minutes of immersion, and then gradually fell throughout the remaining duration of the subjects' exposure.

Figure 30 illustrates the pattern of response for subjects wearing FS, BC, AC, WS and NX on the boat or in the liferaft. During the first five minutes of cold exposure, when the subjects were in the water, skin temperatures declined precipitously as before. But when the subjects climbed out of the water onto the boat or into the raft, mean weighted skin temperatures increased to a level intermediate between preimmersion and immersion values. This was true even for FS, despite the continuous wetting produced by the spray and waves. For NI in the raft,

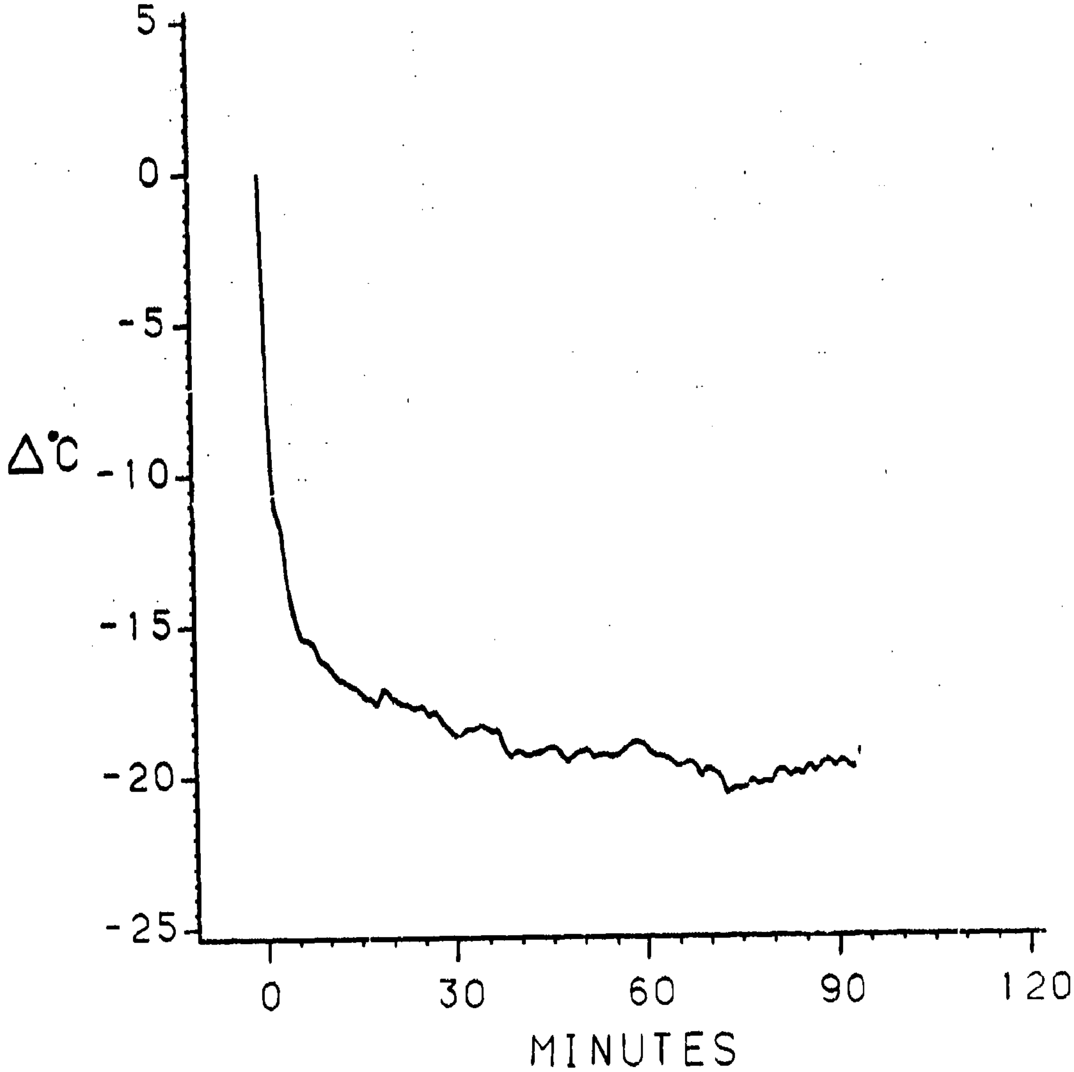

Figure 28. Mean weighted skin temperature change for subject 4 wearing BC in rough seas.

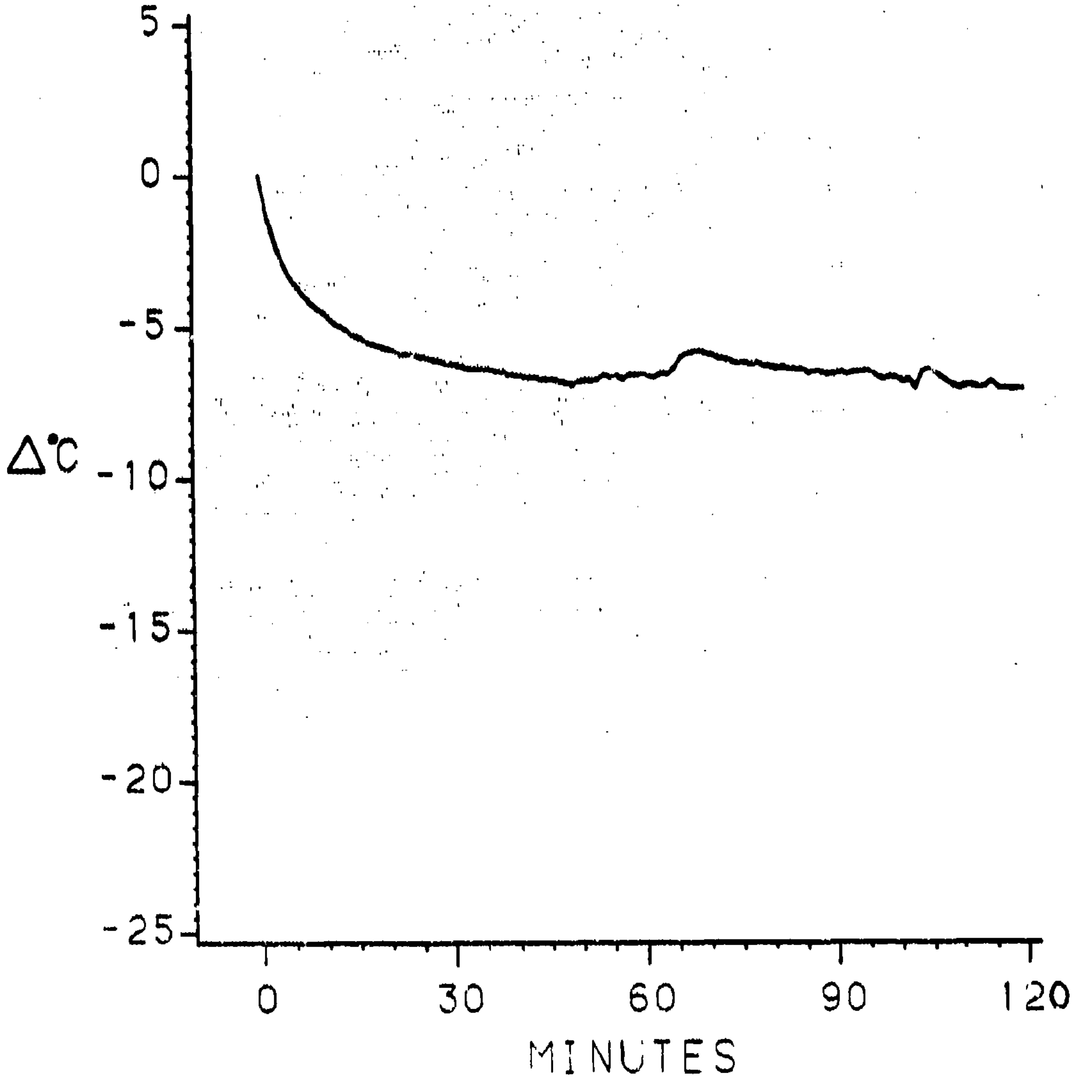

Figure 29. Mean weighted skin temperature change for subject 7 wearing NI in rough seas.

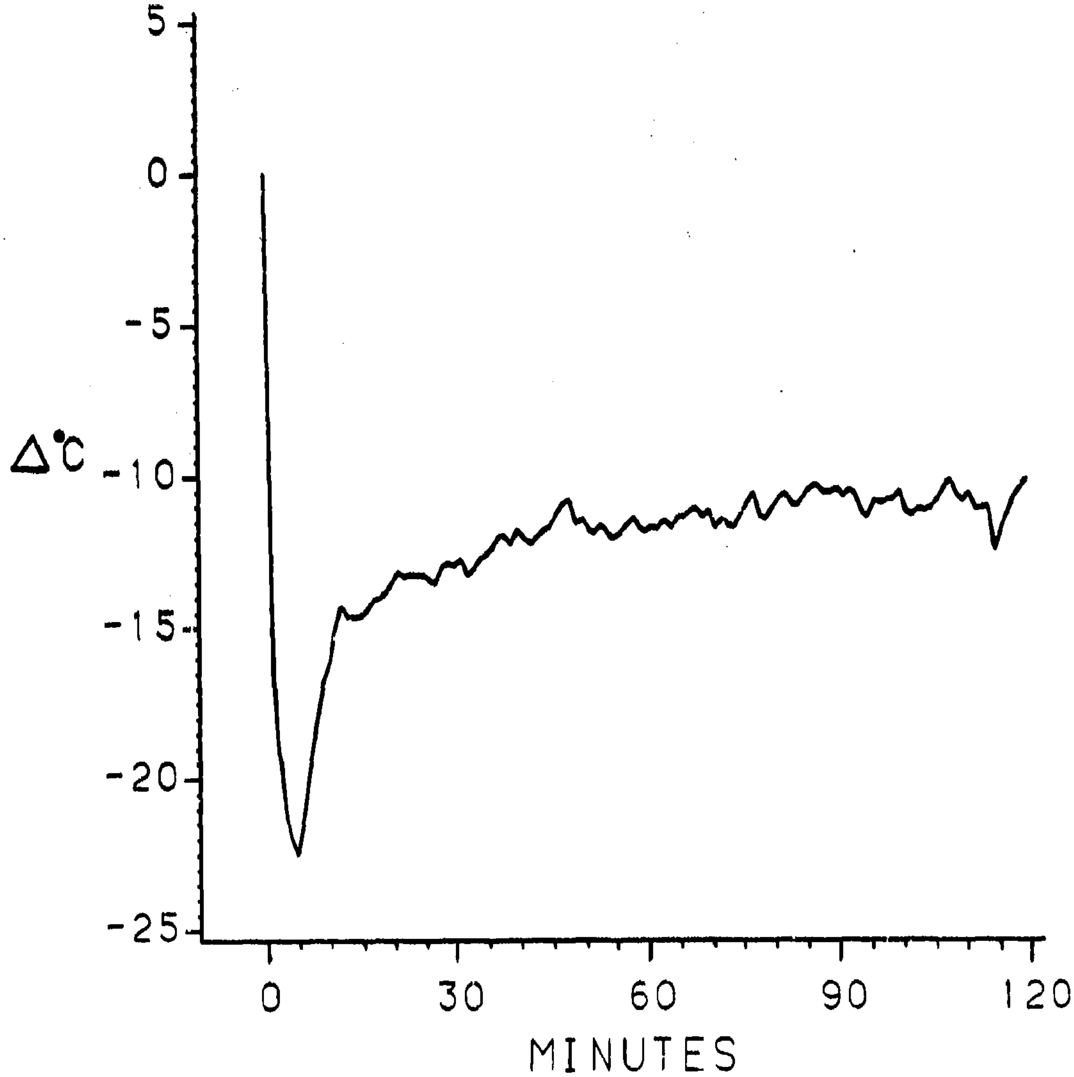

Figure 30. Change in mean weighted skin temperature for subject 8 wearing FS on the overturned boat.

the small initial decline in mean weighted skin temperature was followed by a very gradual increase over the duration of exposure.

Figures 31-33 show the complete set of curves of mean weighted skin temperature over time for all subjects in the three survival environments. The variation among subjects for each garment-ensemble in each environment (reading horizontally across rows) was far less for this variable than it was for rectal temperature cooling rates. The variation among garment-ensembles for each subject in each environment (reading vertically down columns) illustrates the relative degree of protection from the cold provided to the skin by each garment-ensemble.

Figure 34 and Table 9 show the mean decline in mean weighted skin temperature for the subjects during their exposure in each of the garment-ensembles in each of the survival environments. In addition, Table 9 shows the mean decline in mean weighted skin temperature during the first five minutes of cold exposure.

During immersion in rough seas, FS, BC and NX allowed similar declines in skin temperature (21.0, 18.8 and 17.4°C, respectively). However, during the first five minutes of immersion, NX allowed a mean decline in skin temperature of only 7.7°C, compared to 19.0 and 15.8°C respectively for FS and BC. AC and WS allowed mean declines in skin temperature of 15.0 and 12.7°C, respectively, following initial declines during the first five minutes of immersion of 13.8 and 10.8°C, respectively. Finally, NI permitted a mean decline of only 7.7°C over the duration of cold-water immersion, following an initial mean decline of only 3.5°C.

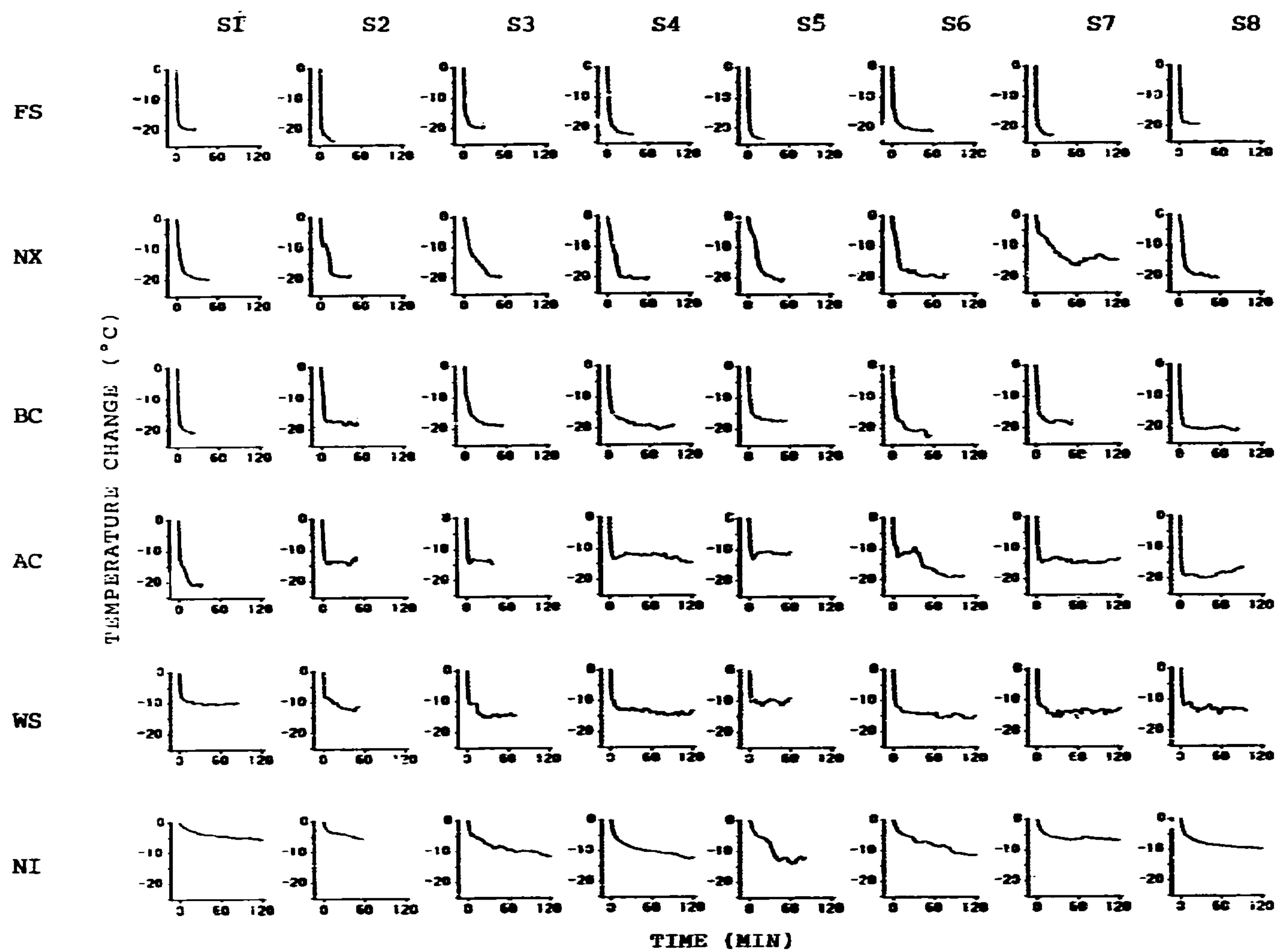

Figure 31. Change in mean weighted skin temperature for each subject (columns) in each garment-ensemble (rows) in rough seas.

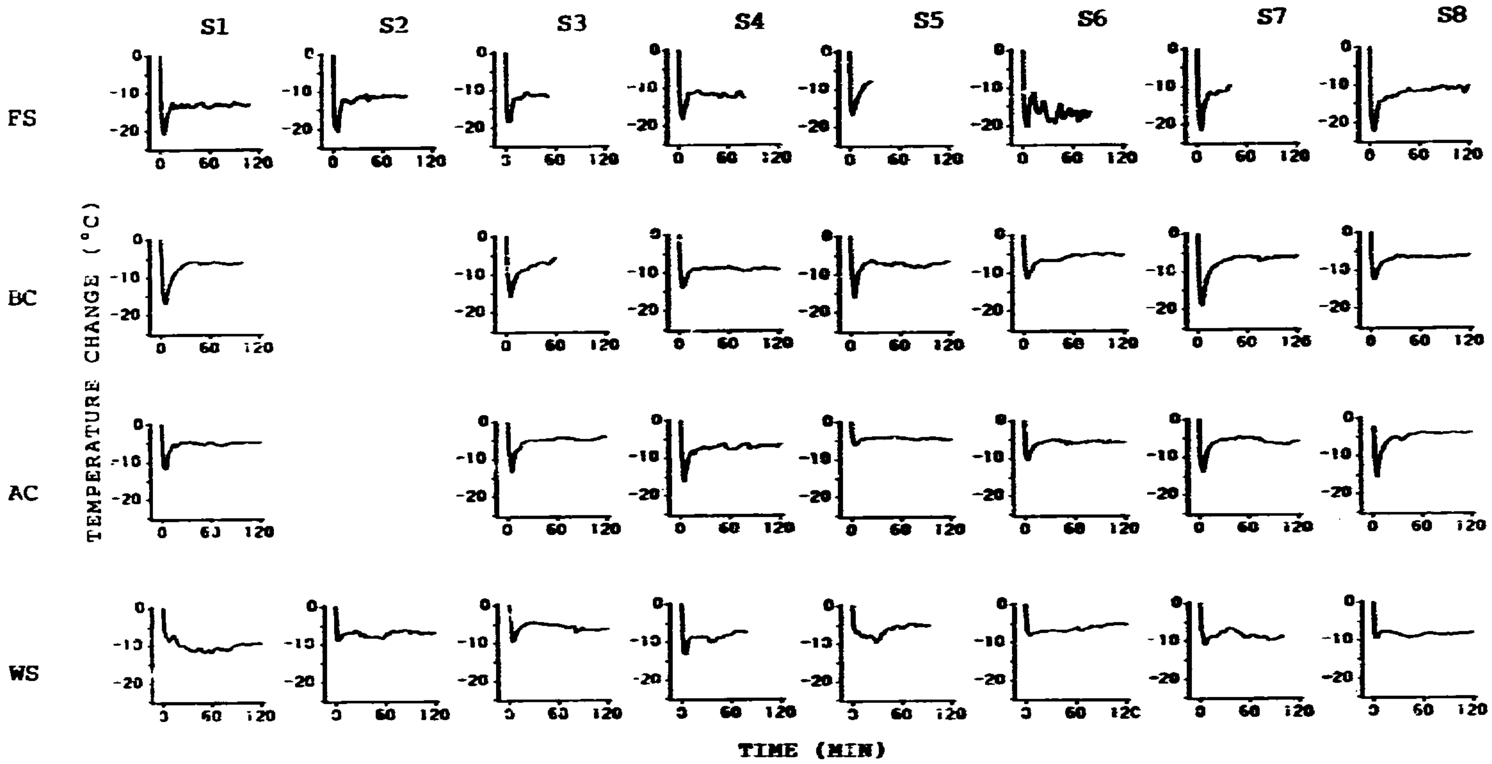

Figure 32. Change in mean weighted skin temperature for each subject (columns) in each garment-ensemble (rows) on the overturned boat. (Blank spaces indicate missing data).

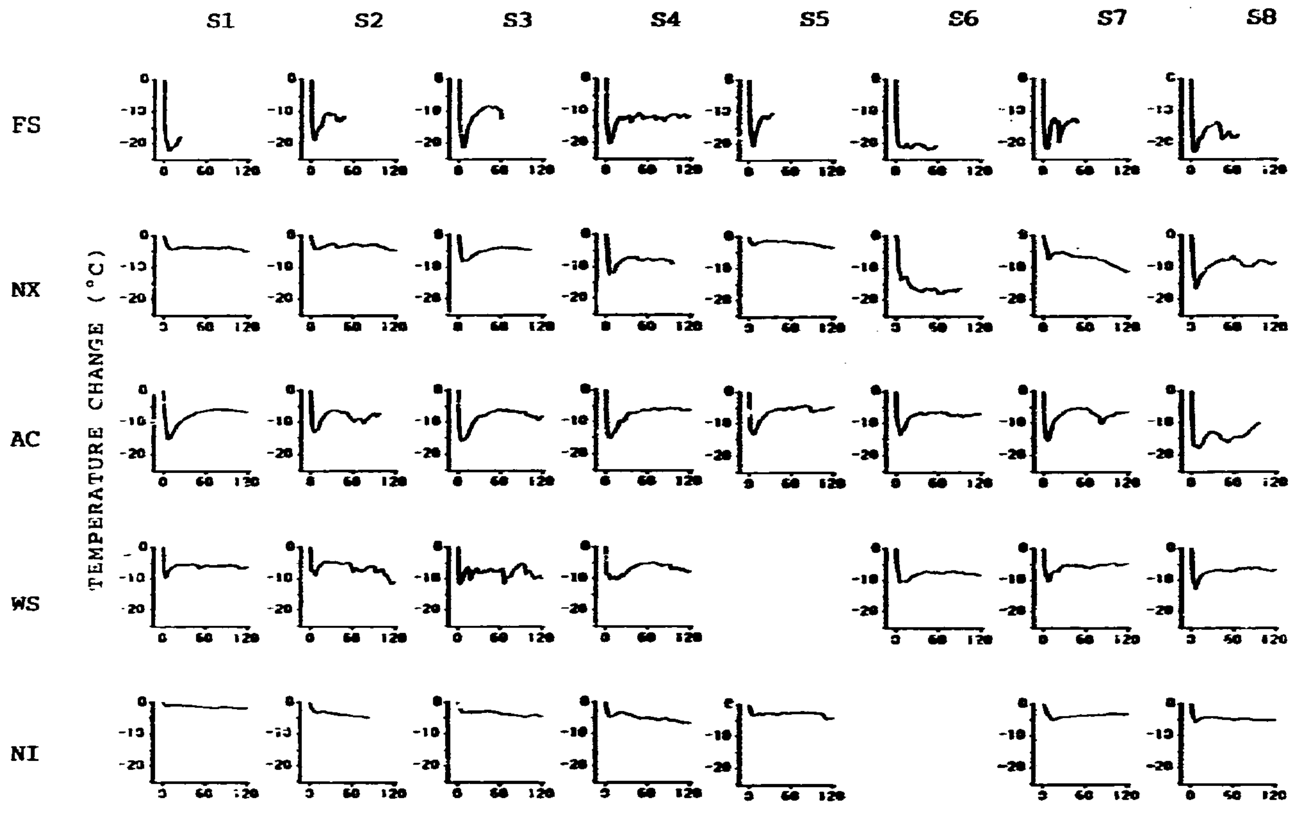

Figure 33. Change in mean weighted skin temperature for each subject in each garment-ensemble in ti cne-man liferaft. (Blank spaces indicate missing data.)

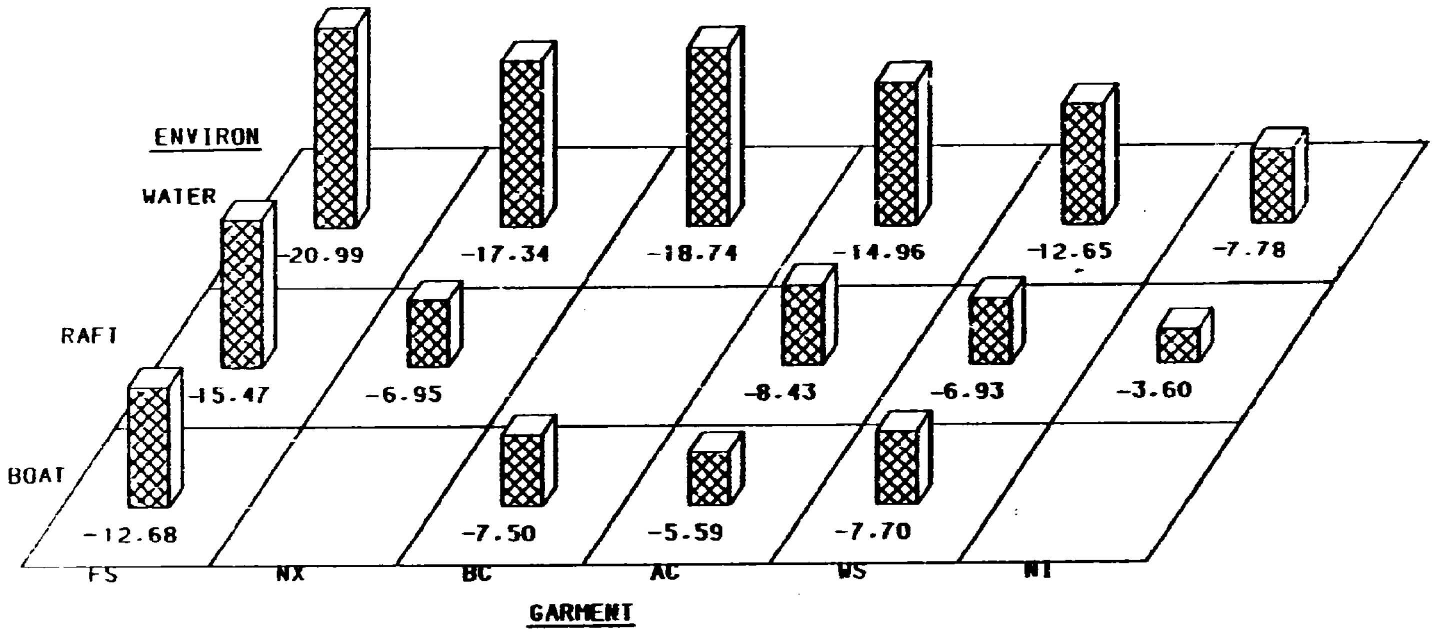

Figure 34. Mean change in mean weighted skin temperature for each garment-ensemble in each survival environment. Blank squares indicate combinations of garment-ensemble and environment which were not tested.

Table 9. Mean Decline in Mean Weighted Skin Temperature*

Garment Ensemble	Entire Duration of Cold Exposure (°C ± SEM)	Initial 5-min of Cold Exposure (°C ± SEM)
Water		
FS	20.99 ± 0.53	19.01 ± 0.73
BC	18.75 ± 0.48	15.77 ± 0.89
NX	17.35 ± 0.73	7.67 ± 0.91
AC	14.96 ± 1.09	13.84 ± 0.93
WS	12.66 ± 0.65	10.80 ± 0.63
NI	7.70 ± 0.77	3.49 ± 0.47
Boat		
FS	12.79 ± 0.63	19.76 ± 0.78
BC	7.51 ± 0.39	15.04 ± 1.04
AC	5.59 ± 0.35	12.43 ± 1.17
WS	7.78 ± 0.58	9.60 ± 0.70
Raft		
FS	15.48 ± 1.34	20.31 ± 0.54
AC	8.43 ± 0.97	14.40 ± 0.66
WS	6.61 ± 0.34	9.59 ± 0.46
NX	6.96 ± 1.63	7.39 ± 1.63
NI	3.60 ± 0.44	3.04 ± 0.48

*Mean weighted skin temperature = (0.3) x Chest + (0.3) x Arm + (0.2) x Thigh + (0.2) x Calf. (ref 53)

Vertical bars indicate groups of garment-ensembles with statistically similar mean declines in skin temperature (per Tukey's multiple comparison test, alpha = .01).

During exposure to cold wind, spray and waves atop the overturned boat, FS allowed a mean decline in mean weighted skin temperature of 12.8°C, which was significantly less than the mean decline of 19.8°C which occurred during the five minutes of cold-water immersion. In contrast, BC, AC and WS allowed mean declines of 7.5, 5.6 and 7.8°C, respectively, over the course of the subjects' cold exposure. For BC and AC, this was about half of the initial mean decline in skin temperature occurring during the first five minutes in the water; for WS, however, the mean decline of 9.6°C during the first five minutes was only slightly more than the mean decline over the whole test.

Similar results occurred for subjects in the liferaft. FS allowed a mean decline in skin temperature of 15.5°C following an initial decline of 20.3°C during the first five minutes. AC, WS and NX allowed mean declines of 8.4, 6.6 and 7.0°C, respectively, over the duration of cold exposure, following initial declines of 14.4, 9.6 and 7.4°C, respectively. Finally, NI allowed only a 3.6°C decline in mean weighted skin temperature over the entire cold exposure, which was slightly (but not significantly) larger than the 3.0°C decline occurring during the first five minutes of immersion.

Figure 35 shows the correspondence between mean rectal temperature cooling rates and mean decline in mean weighted skin temperatures. Garment-ensembles associated with the fastest cooling rates also allowed the largest declines in skin temperatures. The correlation coefficient for the two variables was ($r=0.86$, $p<.001$).

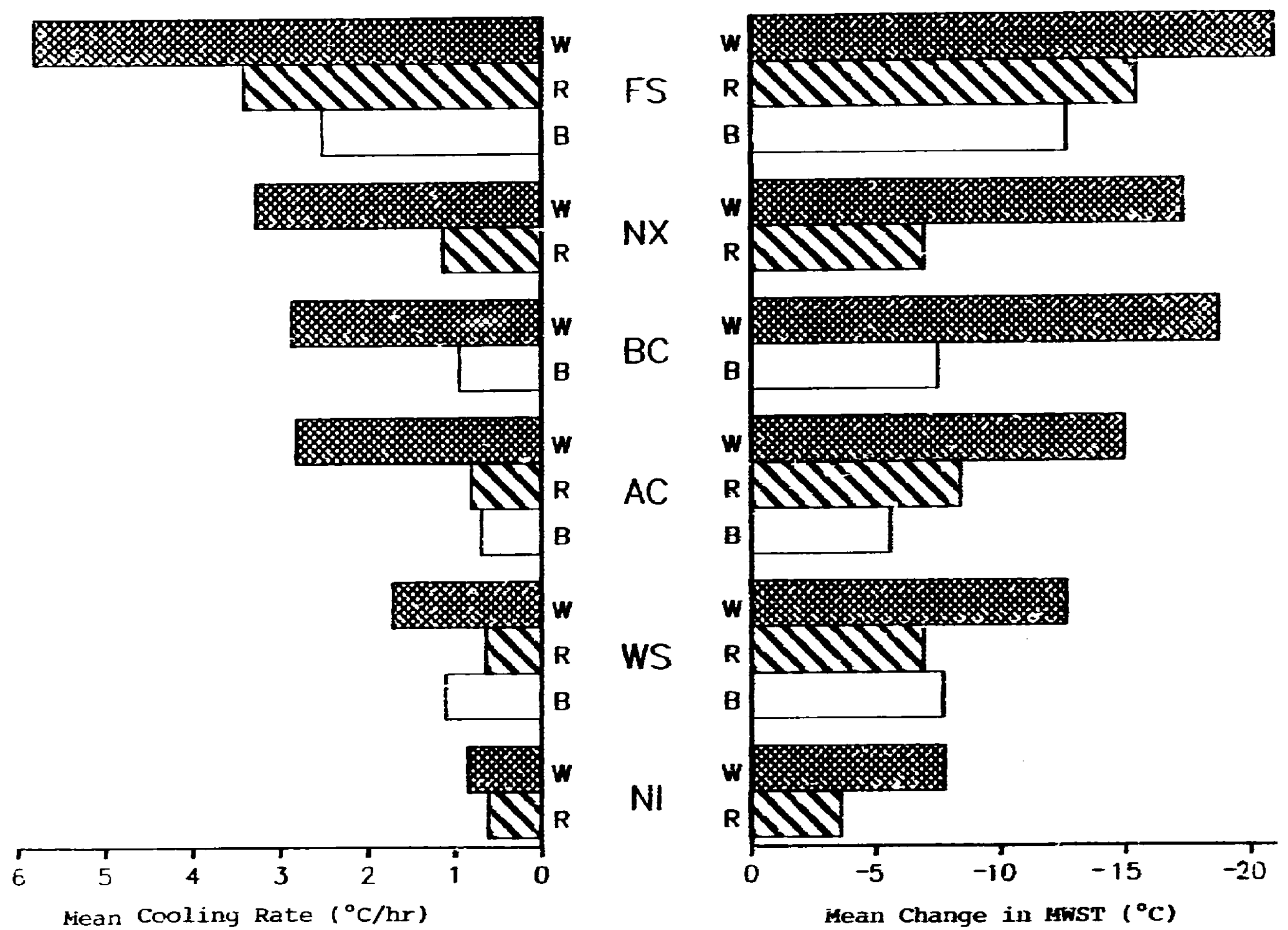

Figure 35. Comparison of mean cooling rates with mean decline in mean weighted skin temperatures (MWST). W=water; B=boat; R=raft. Correlation coefficient r = 0.86.

C. Dry Suit Leakage

Table 10 shows the results of leakage measurements in NI and NX after cold-water immersion or exposure to cold air in the one-man life-raft. The intact dry suit (NI) allowed almost no leakage in either survival environment. The torn dry suit (NX), on the other hand, allowed over 7 kg of cold water to leak into the garment during water immersion, and nearly 3 kg during cold-exposure in the raft. Some of the latter leakage, however, occurred during the initial 5-minutes of immersion prior to raft boarding.

Table 10. Dry Suit Leakage

Garment	Leakage (mean kg water ± SEM)
NI (water)	0.04 ± 0.06
NX (water)	7.19 ± 3.15
NI (raft)	0.03 ± 0.05
NX (raft)	2.78 ± 1.86

D. Subjective Evaluations

Tables 11 and 12 show the subjective evaluations of garment-ensemble performance in each of the three survival environments. In Table 11, flushing of cold water in FS was defined as 10, and all other garment-ensembles were rated relative to this standard. Similarly, in Table 12, the degree of comfort for FS in the water was defined as 1.0,

and all other garment-ensembles were rated accordingly.

Table 11. Subjective Evaluations of Cold-Water Flushing/Leakage and Protection Against Wind and Spray

	Flushing/Leakage of Cold Water (mean score* ± SEM)	Protection Against Wind and Spray (mean score* ± SEM)	
Garment	Water	Boat	Raft
FS	10.00 ± 0.00	1.25 ± 0.16	5.75 ± 0.96
AC	5.75 ± 0.84	7.14 ± 0.94	7.88 ± 0.77
WS	6.00 ± 0.58	6.63 ± 0.73	8.00 ± 0.53
BC	7.13 ± 0.67	7.86 ± 0.91	-
NI	1.63 ± 0.38	-	9.00 ± 0.44
NX	7.00 ± 1.00	-	6.63 ± 1.05

*scores range from 1 (least) to 10 (most); FS was defined as 10 for cold-water flushing

Table 12. Subjective Evaluations of Comfort

Garment	Water	Boat	Raft
		(mean score* ± SEM)	
FS	1.00 ± 0.00	1.13 ± 0.13	1.75 ± 0.53
AC	6.38 ± 0.71	6.29 ± 0.42	7.75 ± 0.73
WS	5.71 ± 0.68	7.25 ± 0.65	7.57 ± 0.37
BC	5.38 ± 0.68	6.14 ± 0.34	-
NI	6.88 ± 0.74	-	8.14 ± 0.55
NX	2.75 ± 0.73	-	5.75 ± 0.94

*scores range from 1 (least) to 10 (most); FS was defined as 1 for cold-water immersion

During immersion in cold, rough seas, the intact Navy dry suit (NI) subjectively allowed the least amount of flushing or leakage of water (mean score 1.63 ± 0.38), which was consistent with the objective measurements of leakage shown in Table 9. The torn dry suit (NX), on the other hand, subjectively allowed a substantial amount of cold-water leakage (mean score 7.00 ± 1.00), again consistent with objective findings. The loose-fitting "wet" garment-ensembles (AC and BC) allowed significant flushing of cold water during immersion in rough-seas (mean scores 5.75 ± 0.84 and 7.13 ± 0.67, respectively). And suprisingly, even the tight-fitting wet suit (WS) subjectively allowed considerable cold-water flushing (mean score 6.00 ± 0.58).

For protection against cold wind and spray, NI in the liferaft had the highest mean score (9.00 ± 0.44) while FS on the boat had the lowest mean score (1.25 ± 0.16). The other garment-ensembles all subjectively provided good protection both on the boat and in the raft, with mean scores ranging from 5.75 ± 0.96 for FS in the raft to 8.00 ± 0.53 for WS in the raft. For all garment-ensembles tested in both the boat and raft environments (FS, AC and WS), subjective scores were higher in the raft than on the boat.

Subjective ratings of comfort for the garment-ensembles during cold-water immersion were highest for NI and AC (6.88 ± 0.74 and 6.38 ± 0.71, respectively), and lowest for NX (2.75 ± 0.73). WS and BC had intermediate mean comfort scores of 5.71 ± 0.66 and 5.38 ± 0.68, respectively. The rating score for FS was defined as 1.00.

For the garment-ensembles exposed to wind, spray and waves on the

boat, mean comfort scores were highest for AC and BC (8.29 ± 0.42 and 8.14 ± 0.34, respectively), and lowest for FS (1.13 ± 0.13). WS was rated slightly less comfortable (7.25 ± 0.65) than were the insulated coveralls.

For the garment-ensembles exposed to cold air and waves in the liferaft, NI had the highest (8.14 ± 0.55) and FS had the lowest (1.75 ± 0.53) mean comfort score. AC and WS had similar high levels of comfort in this environment (7.75 ± 0.73 and 7.57 ± 0.37, respectively), while NX had a slightly lower mean comfort score (5.75 ± 0.94) than did the wet suit or coveralls.

DISCUSSION

A. Comparison of Garment-Ensembles between Survival Environments

The results of this study confirm the hypothesis that survivors of maritime mishaps in rough seas have faster cooling rates and lower skin temperatures if they remain in the water than if they egress from the sea onto an overturned boat or aircraft or into a one-man liferaft. These findings derive from the more than twenty-fold greater thermal conductivity of water than of air at the same temperature (21,33).

This difference in rate of heat flow is highly significant for survivors of maritime mishaps. Unfortunately, however, a widespread misunderstanding of the concept of "wind-chill" often causes the public (and even many medical and rescue professionals) to conclude that survivors have higher heat losses if they are exposed to wind, especially if they are wet, than if they are immersed in water. For

example, informal polls at a recent search and rescue conference and at a recent emergency medical services conference revealed that about half the audience considered exposure to wind in 6°C air to be a greater hazard than immersion in 6°C rough seas.

Wind-chill was the term originally used by Siple and Passel (35) to describe the increase in heat loss from unprotected skin exposed to wind. The term is frequently used in the communication media (e.g. by radio and television weathermen) without regard to exposed versus unexposed skin. This misleads many to believe that the wind-chill temperature applies to both clothed and unclothed areas of the body. Furthermore, common experience during recreational activities at the beach or at swimming pools, where people subjectively feel colder after leaving the water (due to evaporative heat loss from the skin) than they do while swimming, reinforces the misunderstanding. This has occasionally led survivors to abandon a position of relative safety atop a capsized vessel and to re-enter the water, usually with tragic results (1).

Kaufman and Bothe (36), in a recent paper on the effects of wind-chill, confirmed that the higher heat loss associated with increased wind velocity applied only to bare skin. Using wind speeds up to 1.4 m/sec (2.5 knots) and using cooper cylinders filled with water and covered by various types of material from common protective garments, these authors showed that clothing, even wet clothing, prevents the effects of wind-chill.

Analogous results were found in the present study with considerably higher wind velocities (7.5-10.0 m/sec). Similar declines in mean weighted skin temperatures occurred for subjects wearing insulated, but

wet, protective clothing (i.e. WS, BC, AC and NX) whether they were exposed to wind atop the overturned boat or protected from the wind within the one-man liferaft.

When the skin remained dry beneath adequate insulation (i.e. NI), the decline in mean weighted skin temperature in the raft was only half that seen for the other garment-ensembles. Again this was similar to the results of Kaufman and Bothe, who found that wet clothing on their test cylinder doubled the rate of heat loss over that of dry clothing, but that increasing wind velocity did not significantly increase the rate of heat loss from either wet or dry clothing.

Wind increases the rate of evaporation from the surface of wet clothing (33), but when vapor-impermeable insulation is worn between the skin and the surface of the clothing (e.g. closed-cell foam within WS, AC and BC), evaporative cooling does not significantly increase heat loss from the wearer (36). If, however, the wind penetrates the clothing, evaporative cooling from the wearer's body does increase the rate of heat loss. In the present study, subjects wearing FS, a thin garment-ensemble easily penetrated by wind, had approximately twice the decline in mean weighted skin temperature and had two to three times the cooling rate as did subjects wearing AC, BC or WS on the boat or in the liferaft. Compared to NI, which allowed penetration of neither wind nor water, subjects wearing FS had over four times the decline in mean weighted skin temperature and over five times the cooling rate.

Among the three garment-ensembles tested in both the boat and raft environments (FS, AC and WS), cooling rates were faster and skin temperatures were lower for FS and AC in the raft than on the boat.

These differences, however, were not statistically significant. For subjects wearing WS, cooling rates on the boat were significantly faster than in the raft ($p = .048$), but mean declines in mean weighted skin temperatures were similar in the two environments. The results for WS were likely due to a combination of wind penetration through the neck region of the garment (the same area where flushing of cold water occurred during immersion in rough seas) and periodic immersion of the subjects' legs from waves breaking over the capsized boat. Mean skin temperatures from both the thigh and calf were lower for subjects wearing WS on the boat than they were in the raft.

Although not statistically significant, the faster cooling rate of subjects wearing FS in the raft (3.42 ± 0.72 °C/hr) over that on the boat (2.52 ± 0.52 °C/hr) was somewhat surprising. The continuous effects of wind, spray and waves on the overturned boat would be expected to potentiate lower skin temperatures and faster cooling rates than would be seen in the relatively protected environment of the one-man liferaft. The subjective evaluations of protection and comfort for FS, in fact, were higher in the raft than on the boat.

These unexpected findings for FS cooling rates were most likely an anomalous result of experimental design rather than an indication of the relative protection provided by the boat or raft environment for this garment-ensemble. The subjects in this study had extremely fast cooling rates, comparable to those of anthropometrically similar subjects immersed in ice-water in a laboratory tank (54). Consequently, during their first five minutes of immersion, the subjects developed a high initial rate of heat loss. When they egressed from the water onto the

overturned boat, they were no longer exposed to an environment of high heat-conductivity. When they entered the raft, however, they were still partially immersed in cold water and needed about five minutes to bail water out of the raft with their flight helmets. As a result they maintained a high cooling rate for several minutes longer in the raft environment than in the boat environment. The combination of a slightly longer effective period of cold-water immersion with the subjects' fast immersion cooling rate resulted in the end-point of 35°C rectal temperature occurring sooner in the raft than on the boat. Had a lower end-point for termination of cooling been selected or had subjects with slower immersion cooling rates been used, the mean linear cooling rate for FS in the raft would likely have been slower than on the boat.

Evidence for this supposition is seen in Tables 6 and 7, where final cooling rates for FS are slowing in the raft but are increasing on the boat. Although the differences between mean linear and final cooling rates were not statistically significant in either environment, clinical observation of the subjects in each environment correlated well with the measured differences. On the boat the subjects were nearly as uncomfortable as they were in the water. In the raft their disposition was far happier and their level of discomfort was less than in the water, and they actually engaged in play, despite a continuing rapid decline in rectal temperature.

Finally, subjective evaluations of comfort for each of the garment-ensembles in the various survival environments confirmed the objective temperature results showing a greater degree of protection afforded by the boat or raft environment than by water immersion. For all garments,

higher comfort scores were recorded in both the boat and raft than in the water. Comfort scores were highly negatively correlated with both decline in mean weighted skin temperature ($r = -0.79$, $p < .001$) and with mean linear cooling rate ($r = -0.82$, $p < .001$).

B. Comparison of Garment-Ensembles within Survival Environments

The results of this study confirm the hypothesis that "dry" insulative garments provide better protection in rough seas than do "wet" insulative garments, and tight-fitting "wet" garments provide better protection in rough seas than do loose-fitting "wet" garments.

"Dry" insulated garments are designed to exclude water from skin contact. These garments derive their insulation from either the inherent properties of the garment itself (e.g. closed-cell foam used in the construction of immersion suits or other types of dry suits) or from various layers of insulated undergarments worn beneath an outer, waterproof shell of relatively low insulation (e.g. NI in this study).

During previous tests in calm seas, these different types of dry suits demonstrated equivalent protection (11,16). In previous tests in rough seas, a dry suit which maintained its barrier against water ingress provided better protection than did "wet" anti-exposure clothing (30). In the present study, subjects wearing the intact Navy dry suit (NI) during immersion in rough seas had significantly higher skin temperatures and slower cooling rates than when wearing any of the other garment-ensembles. Subjects also had the greatest comfort in the water in NI than in any of the other types of clothing tested.

"Wet" anti-exposure clothing, by contrast, allows water contact with the wearer's skin. When this water is warmed by the wearer, it is no longer a major contributor to heat loss. However, when cold water flushes into a "wet" protective garment, either through the wearer's voluntary movements to maintain airway freeboard or through involuntary movements secondary to wave-action, it displaces the warm water next to the wearer's skin and increases heat loss (28,30,31).

In an earlier study comparing the performance of protective clothing in calm versus rough seas (30), subjects wearing loose-fitting "wet" garment-ensembles (e.g. garments identical to AC and BC) had significantly lower skin temperatures and twice the cooling rates in rough seas as they did in calm water. Furthermore, even subjects who wore a custom-fitted wet-suit (i.e. a tight-fitting "wet" garment, identical to WS used in the present study), had 30% faster cooling rates in rough seas as in calm seas. For both the loose-fitting and tight-fitting garments, flushing of cold water in the rough seas accounted for the differences.

In the present study, subjects wearing the loose-fitting AC and BC garment-ensembles had cooling rates in rough seas which were 64% and 68% greater, respectively, than when wearing WS. Mean weighted skin temperatures were also lower in AC and BC than in WS. In comparison to each other, AC and BC provided equivalent protection in rough seas; cooling rates were nearly identical, and declines in mean weighted skin temperatures were similar. Both AC and BC, however, performed significantly better than did FS; cooling rates in AC and BC were less than half those of FS in rough seas. These findings confirm the significant loss in

effective insulation caused by cold-water flushing, and they also confirm the advantage of wearing insulated clothing in cold water, even though such clothing allows a high degree of flushing.

Interestingly, the subjective evaluations of flushing in WS (6.00 ± 0.58) were not strikingly different from that of AC or BC (5.75 ± 0.84 and 7.13 ± 0.67, respectively), and the evaluations of comfort in the water were also similar for these three garment-ensembles. These results were most likely due to the difficulty in differentiating within the group of "wet" protective clothing the perception of flushing from among the many other unpleasant stimuli which accompanied immersion in cold, rough seas (e.g. periodic facial submersions; continuously cold hands and feet; cold, wet skin; shivering; muscle-cramps, etc.).

The results of this study confirm the hypothesis that a "leaky" dry suit in rough seas provides significantly less protection than does an intact dry suit. Subjects wearing NX, the dry suit with a deliberate tear in its left shoulder seam, had more than twice the decline in mean weighted skin temperature and nearly four times the cooling rate in rough seas than did subjects wearing NI, the intact dry suit. These differences were the result of a mean ingress of over 7.2 kg of water into NX during cold-water immersion. These results confirm the findings of Kaufman and Dejneka (20) in a previous study on identical dry suits. In their study of subjects immersed in 7.2°C calm water, NX allowed nearly twice the decline in mean weighted skin temperature and about 75% faster cooling rates than did NI. The mean ingress of cold water into NX in their tests was over 9 kg.

Other studies on dry suit leakage have shown similar results.

Allan et al. (29), using a thermal manikin and garment-ensembles of approximately the same total insulation as those of the present tests, found a 30-60% decrease in effective insulation when 0.5-3.0 kg of water, respectively, were deliberately leaked into the suit. Hayes et al. (31), using human subjects and a wave tank producing 0.3 m amplitude waves in water temperatures of 8-10°C, found a doubling in cooling rates when leakage was either deliberately introduced into a garment similar to NI or when leakage occurred spontaneously, due to wave action, into a dry suit with inherent insulation of closed-cell foam.

Dry suit leakage has deleterious effects even when subjects are not immersed in rough seas. During exposure to cold air and waves in the one-man liferaft, NX allowed nearly twice the decline in mean weighted skin temperature and nearly double the cooling rate as did NI, due to a leakage of nearly 3 kg of cold water. Although some of the leakage into NX occurred during the initial five minutes of immersion prior to raft entry, further leakage occurred whenever waves broke over the rafts.

The relative magnitude of mean linear cooling rates for the various garment-ensembles in rough seas was nearly identical in the present study to that found in previous tests on rough-water performance (30). Table 13 shows the results from both experiments. The correlation coefficient between like garment-ensembles in the two sets of data is 0.995. The faster cooling rates observed for subjects in the present study in all garment-ensembles were not only due to the colder water but also to the severity of the sea-state. Larger and more frequent waves resulted in a higher incidence of head-submersion in the present study than in the previous tests. Since the head is an area of relatively low

insulation and subsequently high heat loss (55,56), submersion in cold water potentiated total body heat loss.

Table 13. A Comparison of Cooling Rate Data from Rough-Water Tests

Water = 11.1 ± 0.6°C		Water = 6.1 ± 0.4°C	
Garment Ensemble	Cooling Rate (°C/hr ± SEM)	Garment Ensemble	Cooling Rate (°C/hr ± SEM)
FS	3.59 ± 0.49	FS	5.83 ± 0.52
BC	1.96 ± 0.24	BC	2.87 ± 0.39
AC	1.80 ± 0.20	AC	2.81 ± 0.62
WS	0.91 ± 0.11	WS	1.71 ± 0.37
Dry Suit*	0.49 ± 0.08	NI	0.86 ± 0.15

Subjects	Water = 11.1 ± 0.6°C	Water = 6.1 ± 0.4°C
Ht. (cm):	174.4 ± 1.0	175.0 ± 0.8
Wt. (kg):	72.2 ± 0.5	71.7 ± 1.3
% Body Fat:	12.0 ± 0.5	11.1 ± 0.9

*Intact, closed-cell foam insulated garment-ensemble

In the present study, linear cooling rates for all garment-ensembles in rough seas were negatively correlated with both time to onset of cooling ($r = -0.84$, $p < .025$) and with duration of cooling ($r = -0.96$, $p < .01$). In other words, subjects wearing garment-ensembles associated with the fastest cooling rates had both the shortest time delay before their core temperatures began to decline significantly and the shortest duration of exposure to cold water. Time to onset of cooling was also significantly correlated with the decline in mean weighted skin temperature during the first five minutes

of immersion ($r = -0.94$, $p < .01$). These results again confirm the findings of the previous tests in rough seas (30).

Time to onset of cooling in cold water varies with both the physical characteristics of the subject and with the quality and amount of insulation provided by protective clothing (21,33,57). Heat loss to the environment is primarily a function of the difference between ambient and skin temperatures (33,57); heat flow from body core to superficial tissues is a function of both tissue insulation and blood flow (57). Thus, for any given level of cardiac output, lean subjects (i.e. those with little endogenous subcutaneous fat for insulation) wearing garment-ensembles which permit a rapid decline in skin temperature have both a high rate of heat transfer from core to body surface and a high rate of heat transfer from body surface to the environment. The net result is a rapid onset of core temperature decline and a fast cooling rate.

For the garment-ensembles tested in wind, spray and waves on the capsized boat or in cold air and waves in the one-man liferaft, the results of the present study confirm the expected finding that well-insulated clothing (NI, AC, BC, WS and even NX) provides significantly better protection than does poorly-insulated clothing. However, the results fail to confirm the hypothesis that loose-fitting, "wet," insulated coveralls provide better protection than does a tight-fitting wet suit. Subjects wearing AC, BC or WS on the boat and subjects wearing AC or WS in the raft all had similar times to onset of cooling, similar durations of cooling, similar declines in mean weighted skin temperatures, similar linear cooling rates, and similar subjective scores for both protection against wind and spray and for comfort.

These results are surprising in that the total insulation in air of AC and BC would be expected to exceed that of WS. The greater loft of AC and BC (i.e. the amount of trapped air within the layers of the garment) should give these garments an advantage over the tight-fitting wet suit, which retains little trapped air (37-40). Furthermore, the closed-cell foam insulation in BC is significantly thicker around the trunk, a thermally important region of the body (56), than that of either WS or AC. WS, on the other hand, has 50% thicker closed-cell foam in all locations than does AC. If the thickness of the foam were the primary factor in the total insulation of these garments, skin temperature decrements and cooling rates would be ordered AC > WS > BC. Since these variables were found to be nearly equal, other factors were evidently influencing the effective insulation of these garment-ensembles.

Body motion decreases the intrinsic insulation of protective clothing (37,53), since circulation of air trapped within the garment increases convective heat transfer. In addition, physical activity decreases surface air insulation (53). The subjects in the present study were seated atop the boat where they frequently had to grasp the handrails to avoid being washed overboard by the waves. The physical activity involved may have created a pumping effect to increase the flow of trapped air to the environment and, subsequently, to increase convective heat losses in AC and BC (53). Similarly, the subjects in the raft had to frequently bail water in order to maintain the raft's freeboard. This activity may also have created a pumping effect. And the effect of waves impacting on AC and BC may have further contributed to convective heat loss by compressing the garments and temporarily displacing trapped

air. Finally, water from the spray-making apparatus and from waves washing over the boat or into the raft may have entered the loose-fitting coveralls and increased conductive heat losses. The combined effects of these various factors may have reduced the total insulation of AC and BC in air to a level equivalent to that of WS.

In both the raft and boat environments, mean cooling rates for subjects wearing any of the insulated garment-ensembles were slowing by the end of the exposure period. As seen in Tables 6 and 7, the final cooling rates were noticeably smaller than were linear cooling rates for all garments except FS. For AC, in fact, final cooling rates in both environments were negative, implying that subjects wearing this garment-ensemble were actually rewarming at the termination of their tests, despite continued exposure to the cold.

The slowing of cooling rates in both the boat and raft environments was a result of conservation within the garment-ensembles of increased metabolic heat produced by shivering. For the subjects in this study, who were physically fit and who had greater than average muscle-mass, the net result of endogenous heat production (i.e. shivering thermogenesis) combined with adequate clothing insulation was a significant reduction in the rate of heat flow from body core to the cold environment. Less fit individuals, with smaller capacities for shivering thermogenesis (i.e. a smaller percentage of lean body mass) would likely be less successful in slowing their cooling rates in either the boat or raft environments (58).

C. Survival Time Estimates

Estimates of survival time for immersion in rough seas, based on the data from these tests, must be made with extreme caution. The subjects of this study were not representative of the average population, so inferences derived from their cooling rates can only be applied to subjects of similar physical characteristics.

The subjects in this study were all male, so extrapolations to a female population may be unreliable. Some studies, however, have shown that men and women have similar cooling rates (54,59). Since women, in general, have more subcutaneous fat than do men, heat flow from body core to skin is generally slower in women than in men. But women are, in general, smaller than men. They therefore have a larger surface-area to mass ratio, which potentiates heat flow from the body surface to the environment (33). These two opposing factors may balance each other and result in similar cooling rates for men and women.

The subjects in this study were also lean and extremely fit. Both percent body fat (60-63) and physical fitness (64) have been shown to be negatively correlated with cooling rate (and therefore positively correlated with survival time). The subjects in this study thus represent a worst-case survival situation with respect to body fat, but a best-case with respect to fitness.

Finally, only one water temperature was tested in this study. Therefore projections of survival times cannot be reliably applied to other water conditions. Colder or warmer water would likely be associated with shorter or longer survival times, respectively (59,65). But comparison of results in different water temperatures is valid only

for similar subject populations under similar experimental conditions. The high degree of correlation in cooling rates presented in Table 13 from studies in different water temperatures derives from the use of highly comparable subjects wearing identical garment-ensembles in similar sea-states.

Given these constraints, estimated rough-water survival times for the subjects in this study are shown in Table 14. Three different levels of survival time are listed: 1) time to reach a core temperature of 34°C, which some authors feel is the limiting temperature for useful function in cold water (25,31,66) and which has been adopted as the basis for the selection of immersion clothing by the Air Standardization Consultative Committee (comprised of representatives from U.S., Canadian and U.K. armed forces) (67); 2) time to reach a core temperature of 30°C, a temperature at which unconsciousness is probable (11,21,24,33); and 3) time to reach a core temperature of 25°C, a temperature where cardiac arrest is probable (21,68).

Table 14. Estimated Survival Times for Lean Subjects Wearing Various Types of Protective Clothing in Rough Seas at 6.1°C

Garment Ensemble	Estimated Survival Time (hrs) (95% confidence range) Time to Incapacity (T = 34°C)*	Time to Unconsciousness (T = 30°C)*	Time to Cardiac Arrest (T = 25°C)*
FS	0.4 - 1.3	0.8 - 2.6	1.3 - 4.3
NX	0.9 - 2.7	1.6 - 5.2	2.5 - 8.4
BC	0.9 - 2.7	1.7 - 5.5	**
AC	1.0 - 2.9	1.9 - 6.0	3.0 - 9.9
WS	1.6 - 4.7	3.1 - 9.9	4.9 - 16.2
NI	2.9 - 8.8	5.7 - 18.2	9.1 - 30.0

*Body core temperature
**Since this garment-ensemble lacks self-righting flotation, death from drowning will be due to unconsciousness

The assumptions underlying these estimations are as follows: 1) cooling rates are linear, as other studies have assumed (11,17,30,54,59,68); 2) cooling begins after the times to onset of cooling shown in Table 3; 3) initial rectal temperature is 37.5°C; 4) survivors are able to maintain airway freeboard until unconsciousness occurs at a rectal temperature of 30°C; 5) self-righting flotation, used with all garment-ensembles except BC, maintains airway freeboard when survivors are unconscious.

The range of survival times shown in Table 14 derive from the mean result of extrapolating each subject's linear cooling rate. However, over the duration of immersion, mean cooling rates were increasing for FS and NX but were decreasing for NI (see Table 5, final cooling rates).

Therefore probable survival times for a population similar to the subjects in this study may be less than that shown for FS and NX and may be greater than that shown for NI.

The survival time estimates are based not only on cooling rate but also on the time-to-onset-of-cooling. Since both are a function of the inherent insulation of the clothing and of the amount of cold-water flushing within the clothing, the survival times underscore the differences among the various garment-ensembles with respect to tightness-of-fit, thickness of insulation and "wet" versus "dry" characteristics. The estimated survival times again indicate that NI offers the best protection and FS offers the least protection in cold, rough seas. NX, AC, and BC provide approximately the same level of protection, and WS is intermediate between these three and NI.

Survival time estimates for the boat and raft environments cannot be reliably made because the assumption of cooling rate linearity in these environments, beyond the two hours measured in this study, may not be valid. For all garment-ensembles except FS, cooling rates were considerably slower at the end of exposure on the boat or in the raft than were mean linear cooling rates.

D. Estimates of Insulation for the Immersed Garment-Ensembles

Although many studies have measured the amount of insulation in air of protective clothing, only a few studies have attempted to measure immersed clothing insulation (29,69). Several laboratories are currently performing this task with thermal manikins in calm water (70,71). The results show that FS has immersed insulation of 0.06 clo,

NI has immersed insulation of 0.60 clo, and NI without its insulated undergarments has immersed insulation of 0.33 clo (31,69). (Generally, 1.0 clo is the amount of clothing insulation required for a subject of average size to comfortably sit in approximately 20°C still air; mathematically, 1 clo = 0.155°C$\cdot$m^2/W, where m^2 is the clothed surface area in square meters and W is watts of heat flow). By comparison, swimming trunks in calm-water provide about 0.03 clo of insulation (31).

Using human subject data from calm water tests and the clothing insulation measurements from thermal manikin studies in a laboratory tank, Wissler developed a mathematical model for relating core temperature to clothing insulation (72). This model has subsequently gained wide acceptance: the five-nation Air Standardization Coordinating Committee adopted it (67), and Allan used the model for recommending required levels of protective clothing for helicopter crews flying to and from offshore oil operations in the North Sea (25).

Recently, Nunneley, Wissler and Allan (73) used the model to associate various levels of clothing insulation, survivor skinfold thickness and projected survival time (defined in their study as the time to reach 34°C body temperature). For the FS (0.06 clo) in 5°C water, fat subjects (90th percentile skinfold thickness) had a 9-fold greater survival time than did thin subjects (10th percentile skinfold thickness). For immersed clothing of 0.33 clo in 5°C water, the fatter subjects had a 6-fold longer survival time. Furthermore, for clothing insulation of 0.33 clo, 90th percentile body fat subjects immersed in 5°C water had the same predicted survival time as did 10th percentile body fat subjects immersed in 14°C water.

These authors also published a nomogram showing the minimum amount of insulation required at any given calm-water temperature to protect the 10th percentile, male population. Figure 36 reproduces this nomogram along with the projected times to 34°C core temperature for the garment-ensembles used in the present study and for the identical garment-ensembles used in the previous rough-water tests (30). Since the subjects in both studies were close to the 10th percentile of U.S. males with respect to skinfold thickness and body-fat, Figure 36 provides an estimation of the effective insulation in rough seas of the various garment-ensembles tested. That is, the rough-water data plotted on the Wissler-Nunneley nomogram yield insulation values which would be expected if garment-ensembles with the same effective insulation were tested on a manikin in a calm-water laboratory tank. The difference between this effective insulation and the insulation actually measured for a particular garment-ensemble represents, to a large degree, the effects of the rough seas.

The FS garment-ensemble (i.e. flight suit + cotton, thermal underwear, etc.) has an effective immersed insulation value in rough seas of about 0.08 - 0.10 clo. Since the flight suit alone accounts for the 0.06 clo curve on the nomogram in Figure 36, the 0.08 - 0.10 clo estimation is not unreasonable, given the additional insulation of the thermal underwear. Rough seas do not appreciably degrade the small amount of insulation in FS. This finding corroborates the results of previous human-subject tests, where no significant difference between calm-sea and rough-sea cooling rates was found for subjects wearing FS (30).

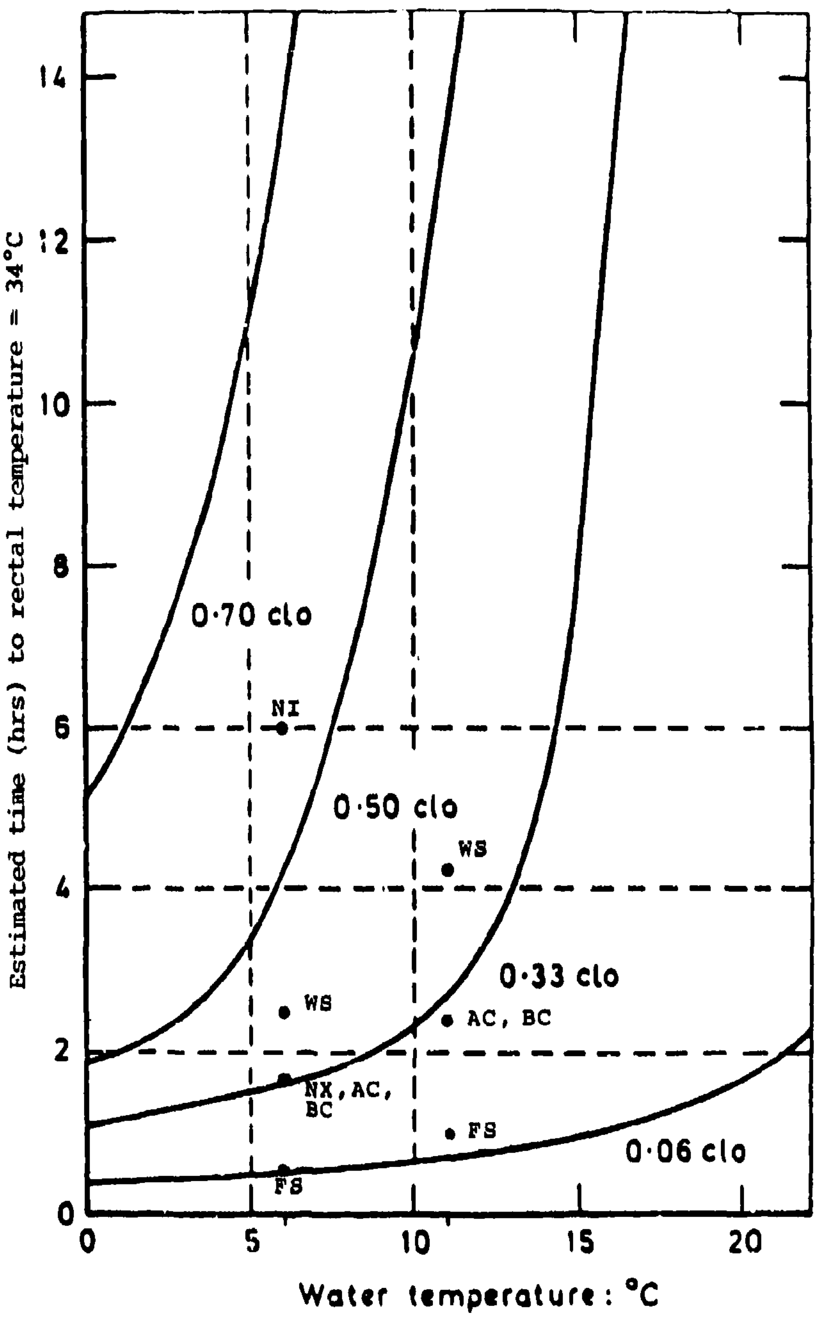

Figure 36. The relationship among calm-water temperature, immersed clothing insulation (clo) and estimated time to T_{re} = 34°C (adapted from Nunneley, Wissler and Allan (73)) for 10th percentile (skinfold thickness) males. Data points are plotted from estimated times to T_{re} = 34°C for garments tested in rough-water at 6.1°C (present study) and 11.1°C (Steinman, et al (30)). Effective insulation can be estimated from interpolation between the curves.

AC, BC and NX have effective immersed insulation in rough seas of approximately 0.30 - 0.33 clo. Extrapolations of cooling rates for these three garment-ensembles in 6.1°C rough water yield times which lie on the 0.33 clo curve; extrapolations for AC and BC in 11.1°C rough seas, however, yield insulation values of about 0.30 clo. Since NI, without its insulated undergarments, has a calm-water, immersed insulation of 0.33 clo (70), the equivalent insulation value for NX in rough seas indicates that leakage of cold water into the dry suit essentially eliminates the additional insulation provided by the layers of cotton thermal and Thinsulite underwear. Similarly, garment-ensembles comparable to BC have a calm-water, immersed insulation of 0.43 clo (71). The 30% reduction in effective insulation to 0.30 clo, estimated from the data in rough seas, correlates with the significant increase in cooling rates of human subjects wearing BC in rough water over that found for calm water (30).

WS has an effective immersed insulation in rough seas of approximately 0.35 - 0.38 clo. The insulation of WS on a manikin immersed in calm-water is 0.63 - 0.65 clo (71,74). The 40% decrease in effective insulation between the calm-water, manikin data and the rough-water, human subject data compares to a 30% increase in cooling rate for subjects wearing WS in rough seas over that in calm seas (30).

Finally, Figure 36 shows that NI has an effective insulation in rough seas of approximately 0.53 clo (compared to 0.60 clo measured on a manikin in calm water). The 12% difference is likely due to the increased heat loss from the subjects' frequent head submersions during rough-water tests, since NI had essentially no leakage in rough seas.

E. Performance of the One-Man Liferaft

The one-man liferafts used in this study were notably successful in reducing the effects of cold-water immersion: for all garment-ensembles, cooling rates were slower and skin temperature declines were smaller for subjects in the raft than for subjects in the water. Furthermore, the rafts provided a degree of shelter from the effects of wind and spray: a subject could lower his head, shoulders and trunk below the inflated collar of the raft and thus avoid exposure to these elements. Finally, the rafts were moderately effective against the effects of breaking waves: a subject could pull the sides of the raft together and minimize water entry into the raft under a breaking wave.

In addition to protecting survivors from the effects of a cold environment, the liferafts provided highly effective flotation. Their freeboard was sufficient to minimize swamping in the breaking waves, but whenever water entered the raft, the raft remained upright and afloat, permitting the subjects to easily bail out the excess water. The rafts were also exceptionally stable; the buttocks of the subjects seated in the raft served as a keel, minimizing any tendency of the raft to capsize. As a result, only 3 out of the approximately 4800 interactions between rafts and waves resulted in raft capsizings.

These findings justify the future use of this one-man liferaft in military helicopter operations. Nearly all rotary-wing aircraft which fly over water have stored liferafts aboard in the event of ditching at sea. Unfortunately, when the helicopter capsizes or sinks, which is often the case following ditching, these stored liferafts are unavail-

able to the crew. The primary advantage of the one-man liferaft tested in this study is its ready availability to a survivor. Since an air-crewman can wear the packed, uninflated raft on his back, he can immediately deploy the raft after he escapes from the helicopter. In contrast to the stored liferaft, the one-man raft meets the primary requirement of any item of personal survival equipment: accessibility when needed.

F. Operational Considerations

The primary focus of this study was on survival at sea: it examined the types of insulated clothing and the options for survivor location which offer the best protection against the effects of cold water and cold weather. The data from these tests may prove useful in the design of training programs for survival at sea and in the selection of operational clothing for survival at sea. These data, however, should be used cautiously, since they derive from a highly select population of human subjects. They may not apply to a general population of larger (i.e. taller, heavier, and fatter) or less fit males, and they may not apply to a female population.

The selection of appropriate protective clothing for military or civilian personnel engaged in maritime aviation or vessel operations over cold water requires consideration of many other factors than just cooling rates and skin temperatures. Among these are:

1) Continuous wear capability

   Operational clothing should be comfortable both at rest and while working; it should not impede mobility or manual dexterity; and it should not induce heat stress when worn in environments of high ambient temperature.

2) Buoyancy

   Operational clothing should have inherent buoyancy or be compatible with personal flotation devices which are reliable, have self-righting capability, and have adequate buoyancy to maintain airway freeboard in both rough and calm seas.

3) Protection of the airway from aspiration of water in rough seas
4) Availability of supplemental protection (e.g. the one-man raft)
5) Ease of donning and donning-time
6) Visibility; storage space for signalling devices
7) Facility of rescue; probable rescue time
8) Facility of underwater escape
9) Flame resistance
10) Maintenance and required storage space
11) User confidence and aesthetic appeal
12) Cost

Protection against immersion hypothermia must be carefully balanced against these other factors, and such balance nec sarily involves compromises. Maximum protection against immersion hypothermia is almost always achieved at the expense of comfort, mobility and reduction of heat stress. Maximum comfort and mobility and minimal heat stress, on the other hand, are usually achieved at the expense of protection in cold water. For example, a dry suit, like NI, offers the best protection against immersion hypothermia; but it may be associated with wearer discomfort from chafing by the neck and wrist seals, and with heat accumulation in the garment. Furthermore, it may require a high degree of maintenance to ensure its integrity against leakage from tears or holes. AC offers less protection immersion hypothermia than does NI, but it is easier to don and maintain. Like NI, however, it may be associated with discomfort from heat accumulation. FS is comfortable, inexpensive, easy to don and maintain, and does not significantly limit mobility; but it offers the least protection against cold water or air. When combined with the one-man liferaft, however, FS provides nearly the same protection as do AC, NX and BC during immersion in rough seas.

Selection of appropriate protective clothing thus requires integration of performance characteristics with logistical support demands. The operational effectiveness of a particular garment-ensemble must be balanced against its operational suitability.

CONCLUSIONS

1) Survivors of maritime mishaps, dressed in any of the garment-ensembles, maintain higher skin temperatures and slower cooling rates if they escape from immersion in rough seas onto an overturned boat or into a liferaft. Survivors exposed to cold wind, spray and breaking waves have significantly less risk from hypothermia than when they are immersed in cold, rough water.

2) A "dry" suit which has adequate insulation and which remains intact provides greater protection against immersion in cold, rough seas than does a tight-fitting "wet" suit. A tight-fitting "wet" suit provides greater protection against immersion hypothermia than does a loose-fitting, "wet," insulated coverall. A "dry" suit which leaks suffers a significant loss in insulation and may provide less protection than even a loose-fitting, "wet," insulated coverall.

3) For survivors exposed to wind, spray and breaking seas atop an overturned vessel or aircraft, a loose-fitting, "wet," insulated coverall does not provide significantly better protection against hypothermia than does a tight-fitting "wet" suit.

4) The experimental one-man liferaft, if worn by an aircrewman as part of his personal survival equipment, can provide highly effective protection against both hypothermia and drowning in rough seas.

RECOMMENDATIONS

1) The results of this study should be used in training programs for maritime personnel to emphasize that exposure to wind-chill is far less hazardous to a clothed survivor, even when wet, than is continuous exposure to cold water.

2) The results of this study should be used in selecting appropriate protective clothing for personnel engaged in vessel or aircraft operations over cold water. However, since these results address only protection from cold-water immersion and protection from cold wind, they should not be given undue emphasis in clothing selection decisions. Other logistical and operational factors must be considered as well.

3) The one-man liferaft should be incorporated into the personal survival equipment of military helicopter crewmen.

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